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6 EUROPEAN MICROWAVE OUTAGES

(BLACKOUT OF GERMAN SCOPE COMM LINKS, OCT 75 THRU FEB 76).

10 Dale T. Chisholm Paul Navrek

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WIDEBAND RADIO BRANCH

1842 ELECTRONICS ENGINEERING GROUP (AFCS)

RICHARDS-GEBAUR AIR FORCE BASE, MISSOURI

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The operation and maintenance functions for the Defense Communications System (DCS) are performed by the military departments. The Air Force Communications Service (AFCS) is responsible for the engineering, installation, operations, and maintenance for approximately sixty percent of the wideband (line-of-sight and tropospheric scatter) systems within the DCS[1].

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the DCS wideband line-of-sight (LOS) system in Central Germany experienced at least one propagation outage. During this time, the Air Force links in the system suffered outage time ranging from 22 minutes to 42 hours. These propagation outages were attributed to temperature inversions.

This report will outline the characteristics of the links that failed, state the difficulties involved with making decisions based on existing data and give AFCS's initial evaluation and potential solutions to the problem. This report will also outline the need for a more in-depth study of the problem.

APPROVAL PAGE

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1. INTRODUCTION

The operation and maintenance functions for the Defense Communications System (DCS) are performed by the military departments. The Air Force Communications Service (AFCS) is responsible for the engineering, installation, operations, and maintenance for approximately sixty percent of the wideband (line of sight and tropospheric scatter) systems within the DCS[1].

During the period betweeen October 1975 and February 1976, several links of the DCS wideband line of sight (LOS) system in Central Germany experienced at least one propagation outage. During this time, the Air Force links in the system suffered outage time ranging from 22 minutes to 42 hours. These propagation outages were attributed to temperature inversions.

This report will outline the characteristics of the links that failed, state the difficulties involved with making decisions based on existing data and give AFCS's initial evaluation and potential solutions to the problem. This report will also outline the need for a more in-depth study of the problem.

2. EXTENT & NATURE OF THE PROBLEM

Table 1 contains a listing of outage dates along with length of the outages. As can be seen, the October, 1975 outages affected more than just the Air Force Scope Comm System. DCS links operated and maintained by the Army, as well as German civilian and government installations found themselves off the air as well. It would appear that if any faulty design, installation or operation procedure could be cited as a cause or contributing factor, then that deficiency is not peculiar to the Scope Comm System or Air Force engineering.

The geographical extent of the problem is illustrated in Fig. 1. The distance from Schoenfeld to Reese-Augsburg is 400 km or more. Taking into account that available information is limited to DCS links, an affected region as large as 500 km in diameter is within the realm of reason. It should be noted that this region encompasses a wide variety of terrain types - from rugged, mountainous areas to rolling agricultural lowlands.

The usual technique (altrouting) of dealing with link outages was thwarted on several occasions during the October outages. This was due to simultaneous outages on three or more links as well as the lack of available circuits on the unafflicted links. Feldberg-Adenau was the only Air Force link reported to have successfully accomplished altrouting of priority circuits during the October outages.

There is little doubt among AFCS Engineers, both in Europe and at Headquarters, that the outages are attributable to some sort of weather effect. During both October and

LINK	OUTAGE DATE	OUTAGE TIME HOURS
Feldberg-Adenau	25Oct75 1645-26Oct75 0600	13:15
	26Oct75 2030-28Oct75 1434	42:00
	28Oct75 1900-29Oct75 0720	12:20
	29Oct75 1548-29Oct75 2045	4:57
	14Nov75 0420-14Nov75 0525	1:05
	28Dec75 1230-28Dec75 1900	7:07
	28Dec75 1945-28Dec75 2045	1:00
	11Feb76 0425-11Feb76 0447	0:22
Feldberg-Schwarzenborn	25Oct75 1945-25Oct75 2115	1:30
	29Oct75 0723-29Oct75 1430	7:07
Schoenfeld-Muhl	27Oct75 2035-27Oct75 2150	1:15
	28Oct75 1230-28Oct75 2215	9:45
	28Dec75 1240-28Dec75 1710	4:30
Muhl-Langerkopf	28Dec75 1110-28Dec75 1810	7:00
	28Feb76 2230-28Feb76 2329	0:59
*Bonstetten-Reese Augusburg	29Oct75 0450-29Oct75 1020	5:30
*Bonstetten-Hohenstadt	27Oct75 1848-27Oct75 2220	3:32
	28Oct75 0025-28Oct75 0750	7:25
	28Oct75 1448-29Oct75 0230	11:42
*Donnersberg-Koeningstuhl	28Oct75 0615-28Oct75 0745	1:30

* Denotes Army links, all others are Air Force.

Table 1. Table of Outages Attributed to Propagation Anomalies

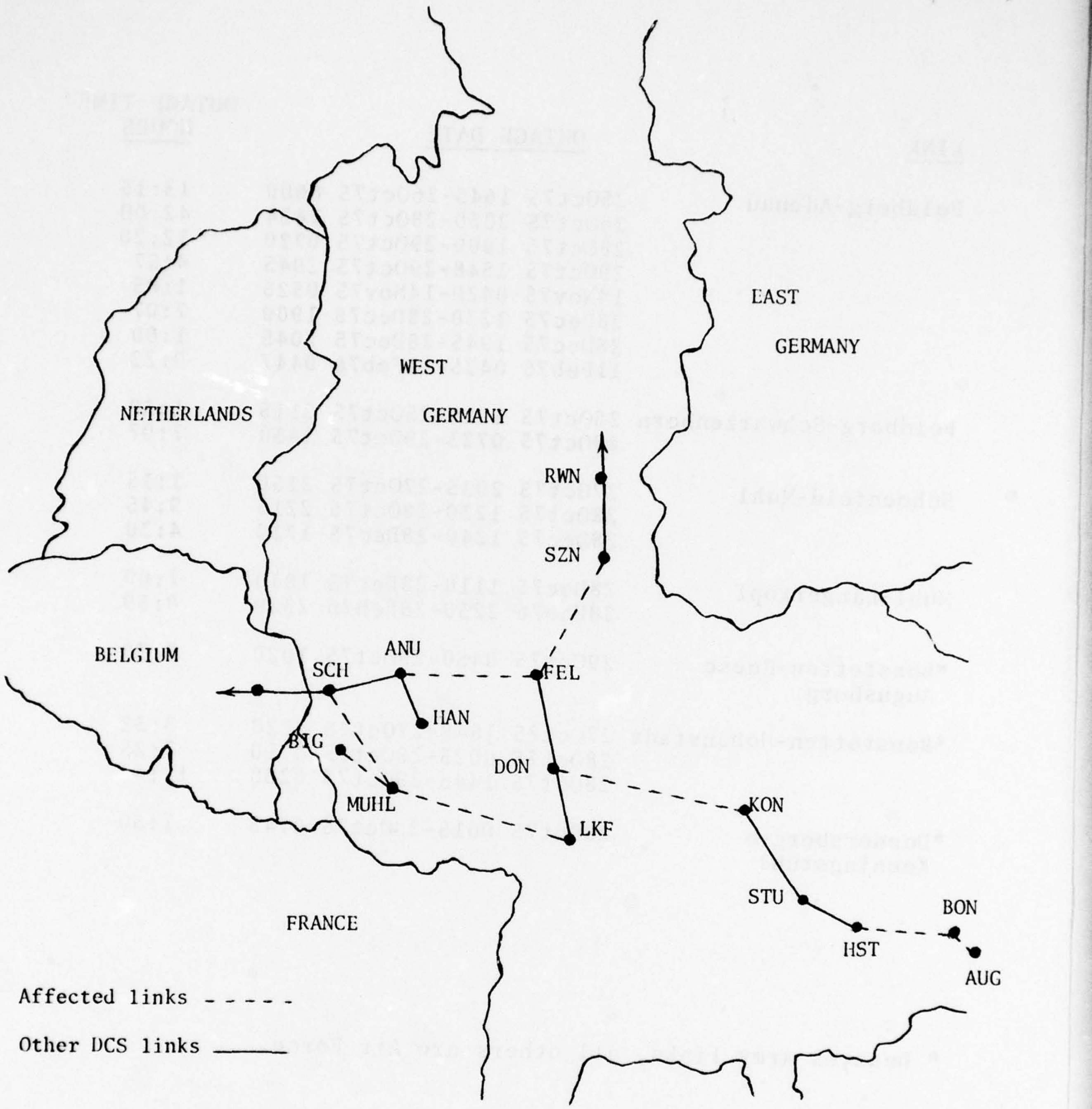


Figure 1. Map of Affected Area

December outage periods, site personnel reported the presence of the meteorological "temperature inversion" phenomena. This condition leads to super refractive propagation conditions and, occasionally, so-called "trapping" conditions. The 2nd Weather Wing (in Europe) first confirmed the high probability of anomalous propagation conditions, a judgement later substantiated by the AFCS Staff Weather Officer. The reported meteorological mechanism involved a high pressure system located over Western Poland. While this system remained in place, dry, high altitude air descended as it circulated around the system and warmed as it descended. This warm, dry air trapped cooler, moist air near the ground, resulting in the aforementioned temperature inversion and superrefractive conditions. The AFCS Staff Weather Officer indicates that the unusual factor is not the occurrence of such a condition nor its severity, but the persistence of this particular occurrence. The fact that the outages apparently recurred in December 1975, and perhaps in February 1976 would seem to indicate that some factor besides normal fading affects these links.

Regardless of what weather conditions caused the outages, the question of their severity remains. The information available at AFCS Headquarters indicates that the links reporting "outage" were unusable during the outage period. In most cases, this means that received signal levels (RSL's) were below the FM threshold of the receiver, although in some cases the presence of recurring deep, rapid fades would render the link equally unusable.
During the October outage period other links in the region (notably Feldberg-Langerkopf) experienced severely depressed

RSL's, even to the point of falling far below desired noise standards, but remained on the air and did not report an outage. This underscores the conclusion that the outages were more than simply prolonged fades of 20 or 30 dB.

3. LINK ENGINEERING

As already mentioned, a total of seven links suffered propagation outages at some time between October 1975 and January 1976. Of primary concern here are the four links engineered, installed, operated and maintained by the Air Force as part of the Scope Comm System. These four are Muhl-Schoenfeld, Muhl-Langerkopf, Feldberg-Adenau and Feldberg-Schwarzenborn. The remaining three are Army links for which the engineering and performance data is not available at Headquarters AFCS, and which were not intended to meet the stringent Scope Comm performance standards.

Scope Comm, as part of the DCS, was designed against applicable DCA circulars and Military Standards - specifically DCAC 330-175-1, now largely superseded by MIL-STD-188-313. While these standards do not contain specific references to availability, availability can be derived from the specification for "short term mean noise".

The short term mean noise power in any 4 kHz channel carried on an LOS link cannot exceed -35dBm0 for more than an accumulated two minutes in any month. Since this noise level will be exceeded if received signal is lost, path outage times in excess of two minutes during the worst month cannot be tolerated. This implies a worst month outage probability of .000046 or less. Recent investigations[3] indicate that outage probability, reckoned on a yearly basis, is about one-fourth of the outage probability indicated during the worst month of that year.

Hence the _yearly_ outage probability in this case is .00001, which is equivalent to six minutes of outage per year or 99.999% ("five nines") path availability. The five nines figure is in good agreement with the stated Air Force objective of four nines reliability for an overall system[1] - if each of the 13 radio hops in the DCA Standard LOS Radio Transmission Reference Section has five nines reliability, then the total section would have slightly less than four nines reliability. Consequently, the five nines performance figure was used as the standard for Scope Comm system engineering.

To translate five nines path availability into terms of fade margin, diversity separation, etc. it is necessary to return to the work of W. T. Barnett and A. Vigants, as condensed in the GTE - Lenkurt Handbook, _Engineering Considerations for Microwave Communications Systems_[3]. Evaluation of their results shows that five nines availability should be achieved on even very long (100 km) links with typical (10m) space diversity separation in adverse locations if fade margins of 40dB are provided. This fact gave rise to the specification of 40dB margins and 30 foot spacing for all Scope Comm links.

With the exception of the long hops, there was nothing unusual or novel about the engineering of the Scope Comm links in Germany. While it is the usual commercial practice to provide paths roughly 50km in length, five of the German Scope Comm paths extended from 70 km to 115 km. Nevertheless, these five were judged to have adequate fade margins and Fresnel clearances to meet availability standards. The fact that four of these five long paths

later suffered propagation outages could be significant and is discussed elsewhere in this report.

Table 2 summarizes the RF path parameters of the five long links. Notice that the large fade margins yield very small outage probabilities. A more detailed presentation, including expected RSL distributions and path profiles is contained in Appendix A. The median RSL values were predicted using the equipment presently installed and the RSL distributions were derived from the Barnett and Vigants equations.

The question invariably arises as to whether Scope Comm could have avoided or alleviated the October outages through better design. Even though several Scope Comm links are considered to be long, they were all designed according to the best available technical methods, using safety margins in excess of normal commercial practices and indicated requirements. When the Institute of Telecommunication Sciences (ITS) independently evaluated the German portion of Scope Comm, they found the system "overdesigned" - and even suggested that diversity protection was not needed (in most cases) to achieve the desired objectives.[4]

LINK		DISTANCE (KM)	FREQ (GHZ)	$K_{.6}$ (Note a)	ANTENNA			PREDICTED RSL (dBm)	FADE MARGIN (dB)	PREDICTED OUTAGE TIME(%)
FROM	TO				SIZE (FT)	GAIN (dB)	BEAMWIDTH (DEGREES)			
MUHL	SCHOENFELD	81	8	0.62	10	45.5	0.85	-31.7	47.2	0.0000045
MUHL	LANGERKOPF	73	8	0.59	10	45.5	0.85	-32.1	46.8	0.0000037
FELDBERG	ADENAU	103	8	0.64	10	45.5	0.85	-31.7	47.2	0.000012
FELDBERG	SCHWARZENBORN	100	8	0.61	10	45.5	0.85	-30.7	48.2	0.0000067
FELDBERG	LANGERKOPF	115	4.5	0.67	15	44.1	1.05	-33.2	45.7	0.000021

All transmitters have output power of +37 dBm (5 watts).

(a) Earth radius factor (K) for 0.6 first Fresnel zone clearance.

Table 2. Path Engineering Summary

4. AVAILABLE DATA

The data available for the study of this problem - radio performance data as well as meteorological readings - is too incomplete and inadequate for identifying a workable solution, much less evaluating a particular solution's long term utility.

a. METEOROLOGICAL DATA.

Weather data is principally collected for two purposes: local weather prediction and as an aid to flight operations. Information on the radio refractive index only appears as a byproduct of these two goals.

The radio refractive index can be expressed as a function of temperature, pressure and relative humidity in the atmosphere. It is the gradient (derivative with respect to height) of the refractive index which affects radio propagation conditions. Thus it becomes necessary to sample conditions at several heights so as to approximate the gradient, a procedure normally accomplished via the use of radiosonde balloons.

Several hundred radiosonde stations are located worldwide. The use of radiosonde observations in radio propagation studies suffers from several important shortcomings.[6]

(1) Radiosonde sites are seldom - if ever - located near LOS radio sites. The problems of extrapolation to a site 100 km or more away, and at a different ground elevation, are not trivial.

(2) The radiosonde balloon has a very rapid initial rate of ascent. As a consequence, altitude information has a fairly large tolerance. Furthermore, the sequential sampling of parameters means that a given set of temperature, humidity and pressure readings may have actually been taken at significantly different heights. This is compounded by the "response lag" associated with most sensors.

(3) As a result of ascent rate and sampling period, very few measurements are made in the lowest few hundred meters of the atmosphere. This is of no consequence to the meteorologist, whose interest extends to several kilometers in height. A radio trajectory may cover only 300 or 400 meters, vertically. The intensity and position of boundaries and layers only 50m thick - severely moderated on the radiosonde record - are important in propagation studies.

The radiosonde data obtained by the AFCS Staff Weather Office following the outages indicated the probable presence of a moderately superrefractive layer (associated with so-called "blackout fades"). In light of the factors mentioned above, this layer could have been much more severe, although whether it was at a proper height to affect the radio links is uncertain.

Nothing more regarding atmospheric refractivity can be legitimately deduced from the radiosonde records. The lack of resolution and methods of measurement preclude any additional conclusions.

b. RADIO PERFORMANCE DATA.

The radio performance data used in the outage study came about as the spin-off of another effort, the Performance Monitoring Program (PMP). Although not considered adequate, the PMP data was used because it was the only data available.

The PMP data consists of Idle Channel Noise, RSL, Baseband Loading and Impulse Noise Measurements taken manually on a daily basis. It is intended to identify the gradual degradation of equipment over a period of many months. It has several characteristics which makes it poorly suited for studying these outages.

(1) It provides only a single figure, presumably the better of the two receivers. No information is supplied as to fading characteristics or differences between receivers.

(2) The readings are taken only once a day, using a fairly long averaging period. The daily readings easily miss outages of as long as twenty hours or more, and totally fail to provide data with useful resolution in the important few hours preceding and subsequent to an outage. The long averaging period gives misleading indications when short, very deep fades render the link unusable while the average RSL remains fairly high.

(3) The method of RSL measurement is not conducive to accuracy at low RSL's. Several factors which contribute to the uncertainty are the following:

(a) RSL is read from a panel meter which monitors the radio's Automatic Gain Control (AGC) voltage.

(b) An identified defect in Scope Comm radios which places the AGC panel meter at an unknown, fluctuating ground potential.

(c) The uncertainties of "eyeball averaging."

(d) The fact that RSL is only recorded once a day, at varying times.

These factors may introduce a five dB variation in RSL measurements. Such an error averages out over the course of many months but is significant on a day-to-day basis.

(4) PMP data is taken between selected stations, not for each link. Unmanned sites, and sites with very meager channel breakouts are not readily adaptable to the PMP system. If a PMP section involves two or more radio links, RSL data is often not even taken; if it is taken, only information on the one-way propagation of the first adjacent link is provided. Figures 2 through 9 show the daily RSL's as reported to PMP during late 1975 and early 1976. Figure 2 shows the Muhl-Schoenfeld RSL from two weeks before the October outages to three weeks after the December incident. Figures 3 and 4 show the period around the October outages in more detail. Figures 5 and 6 show the readings from two weeks before the October outages through the single outage on 28 February 1976 (the latest data available at the time of compilation) on the Muhl-Langerkopf link. Figures 7, 8, and 9 give, for comparison, RSL readings on three links in the affected region which did <u>not</u> report outages.

Except for (perhaps) a long-term degradation of RSL on the Muhl-Schoenfeld link, nothing appears intuitively obvious from these plots. All the links show sharply lower RSL's in late October (around rayday 300); some of the links show even lower RSL's on non-outage days, though. This data will be discussed further in the next section, DATA EVALUATION.

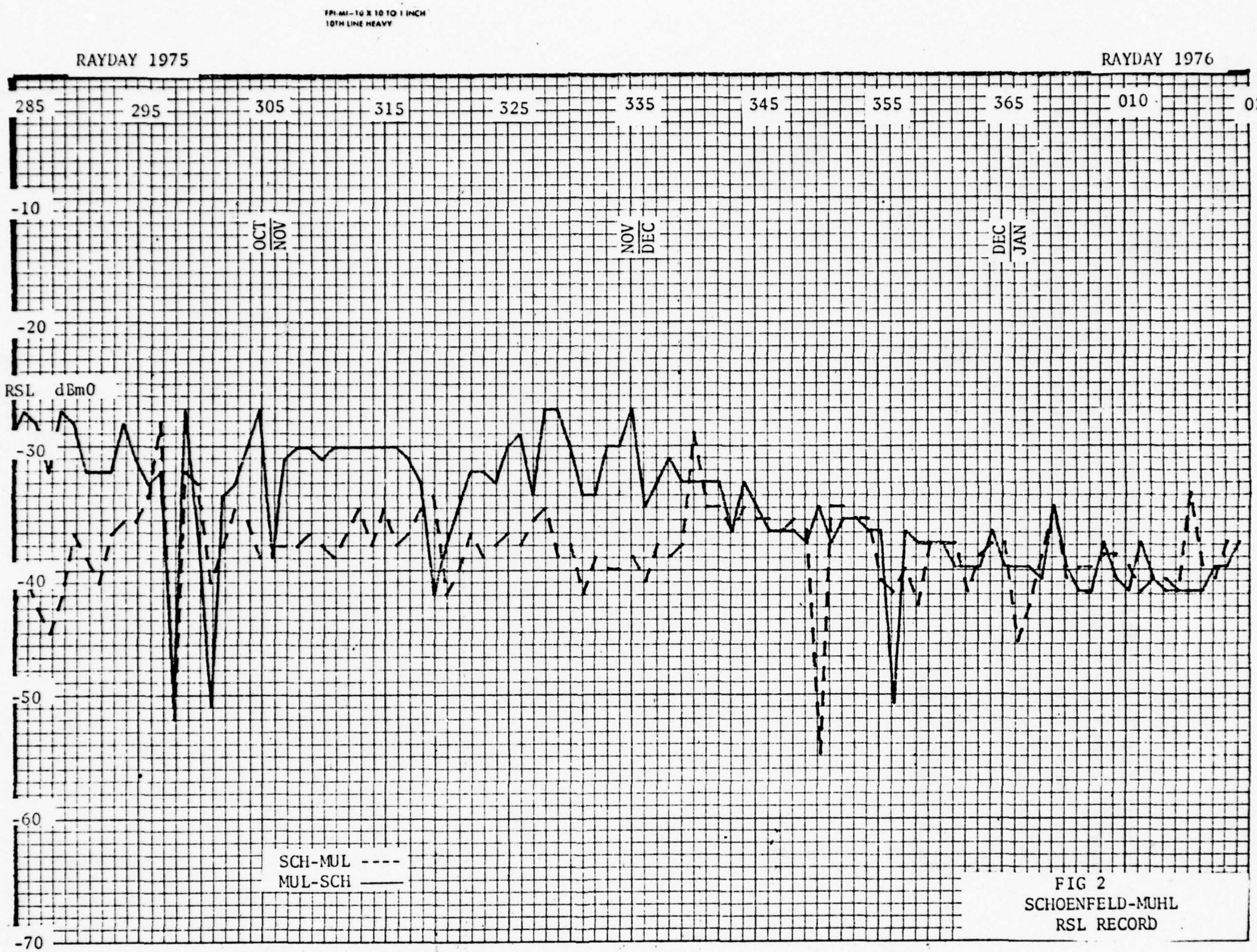


FIG 2
SCHOENFELD-MUHL
RSL RECORD

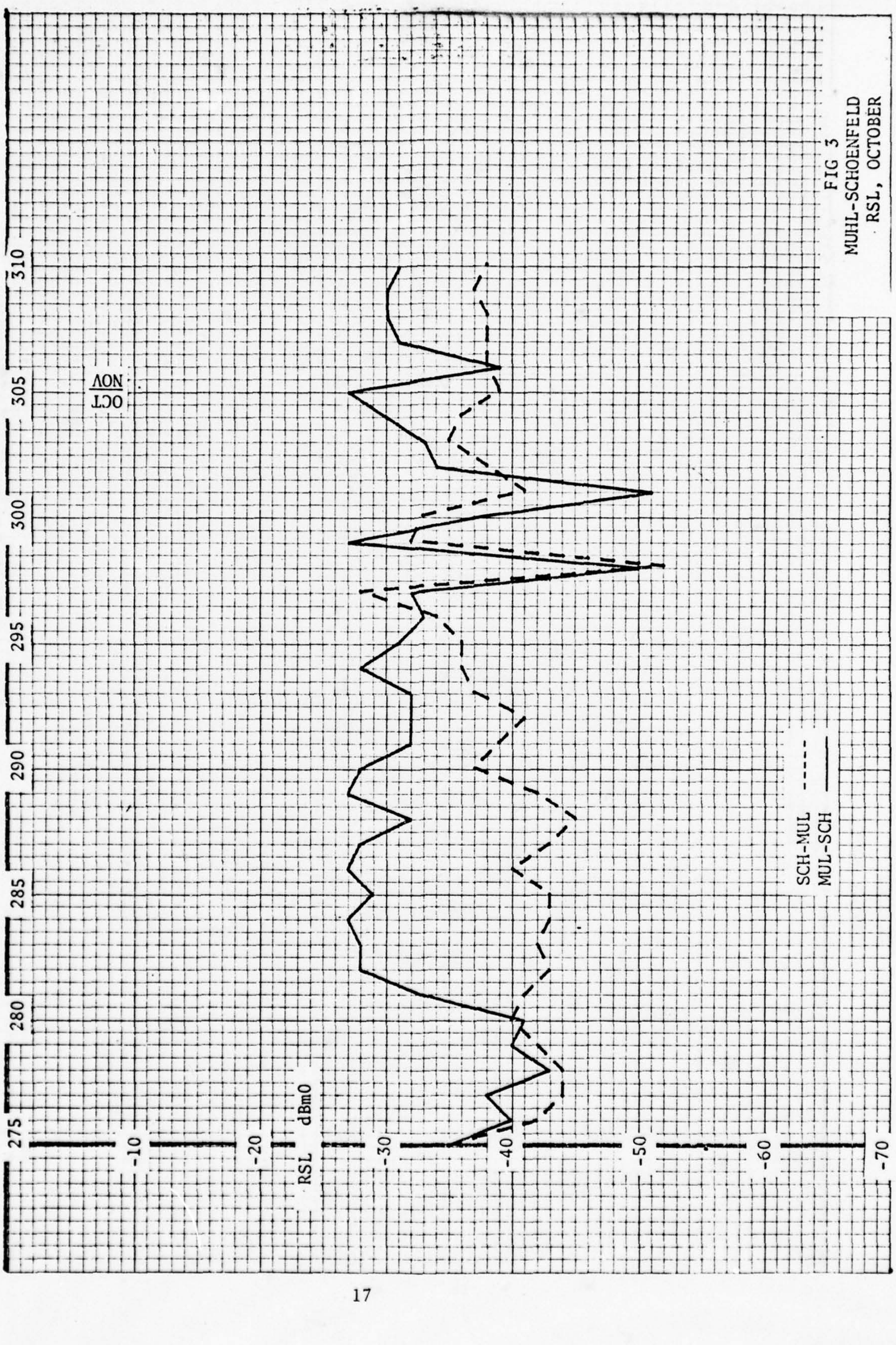


FIG 3
MUHL-SCHOENFELD
RSL, OCTOBER

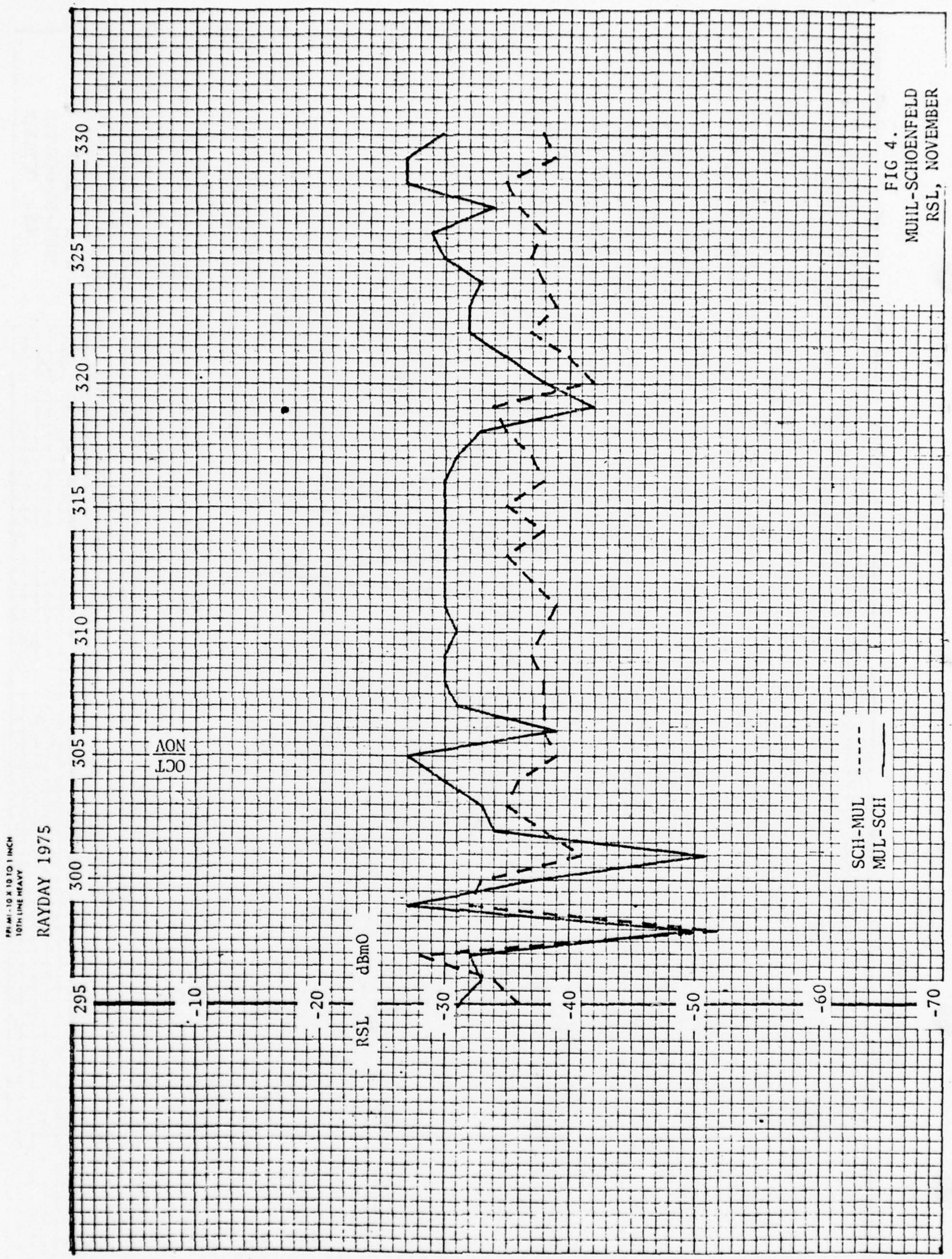


FIG 4.
MUHL-SCHOENFELD
RSL, NOVEMBER

FIG 5
MUHL-LANGERKOPF
RSL RECORD

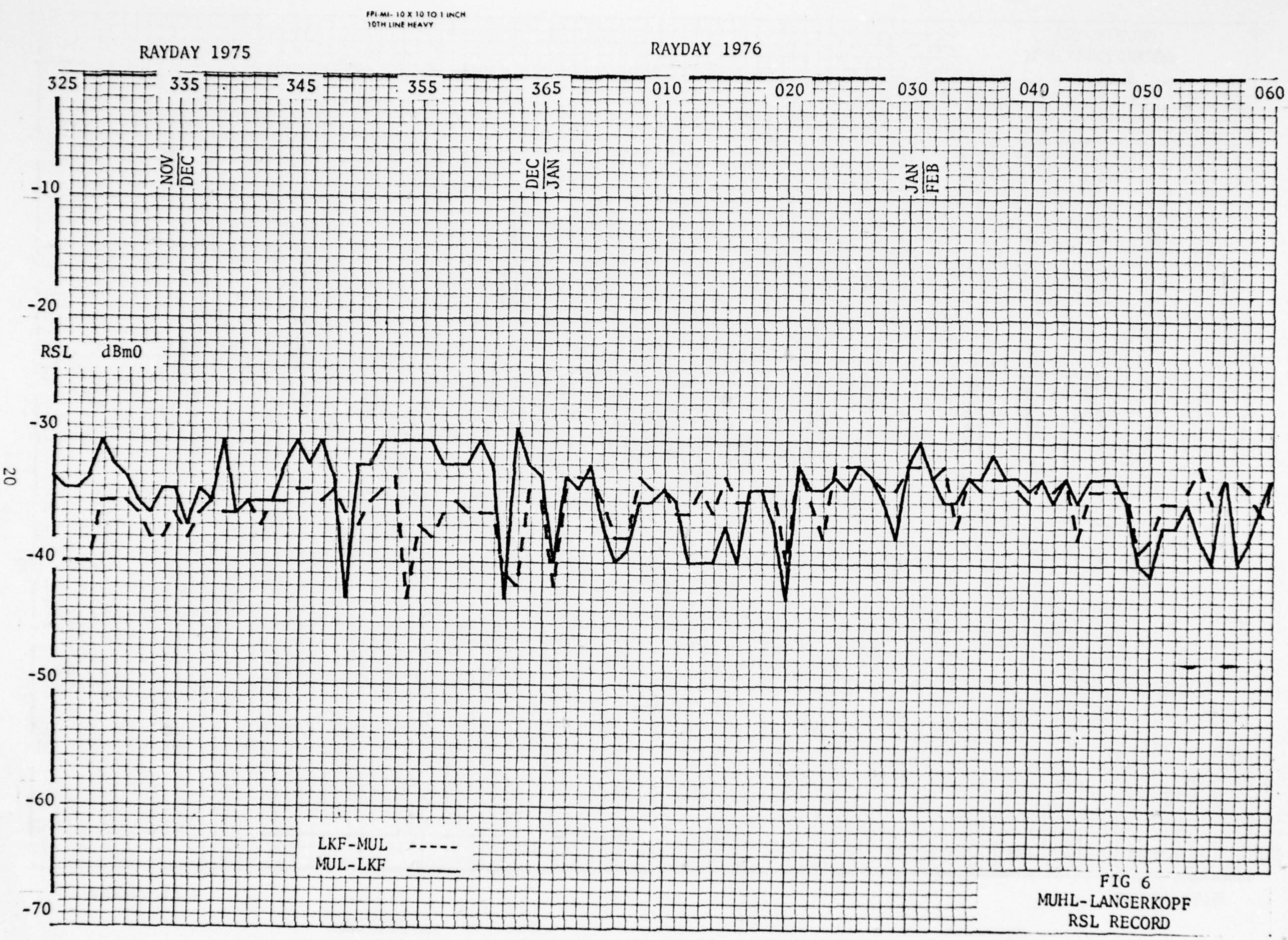


FIG 6
MUHL-LANGERKOPF
RSL RECORD

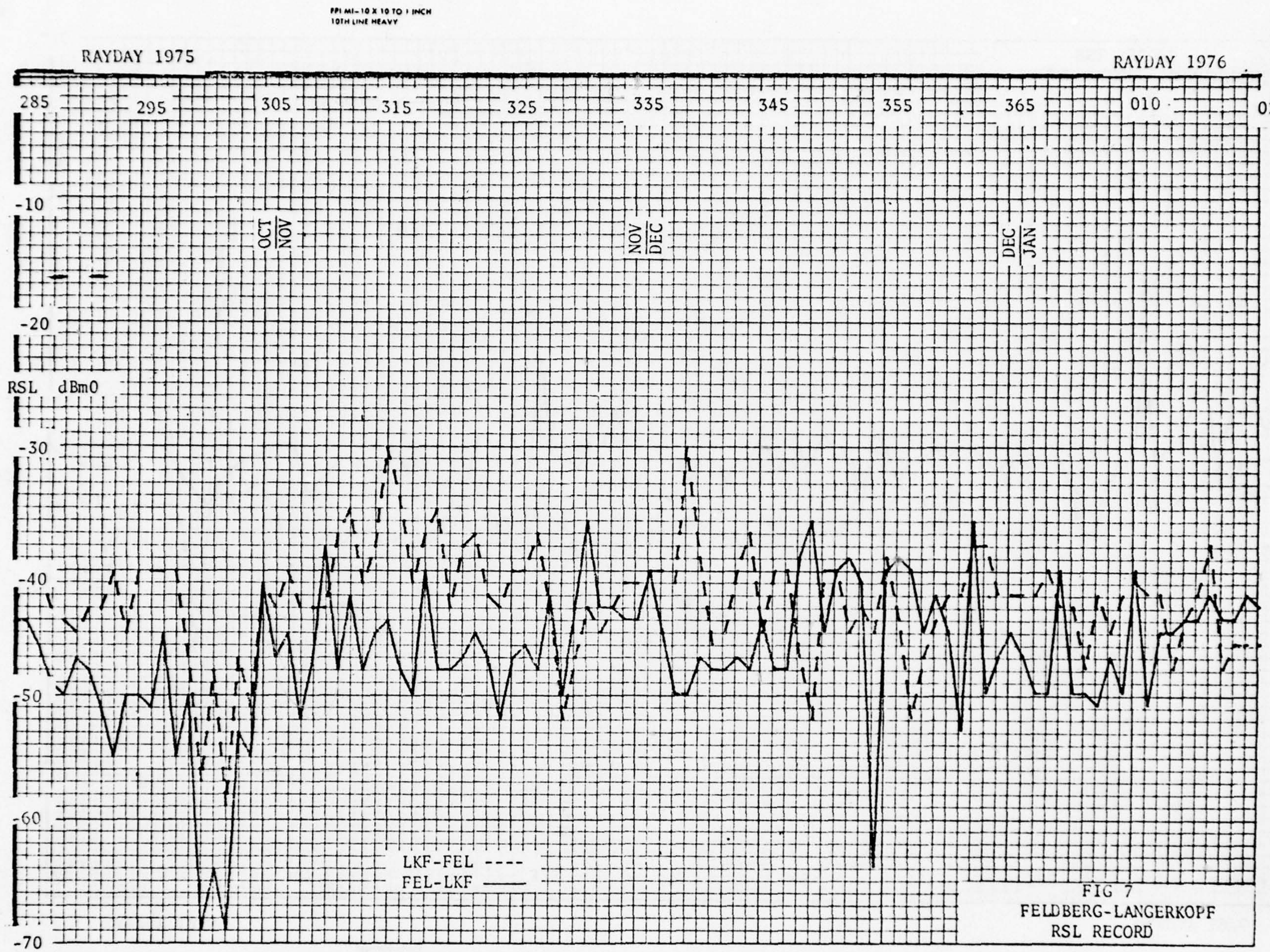


FIG 7
FELDBERG-LANGERKOPF
RSL RECORD

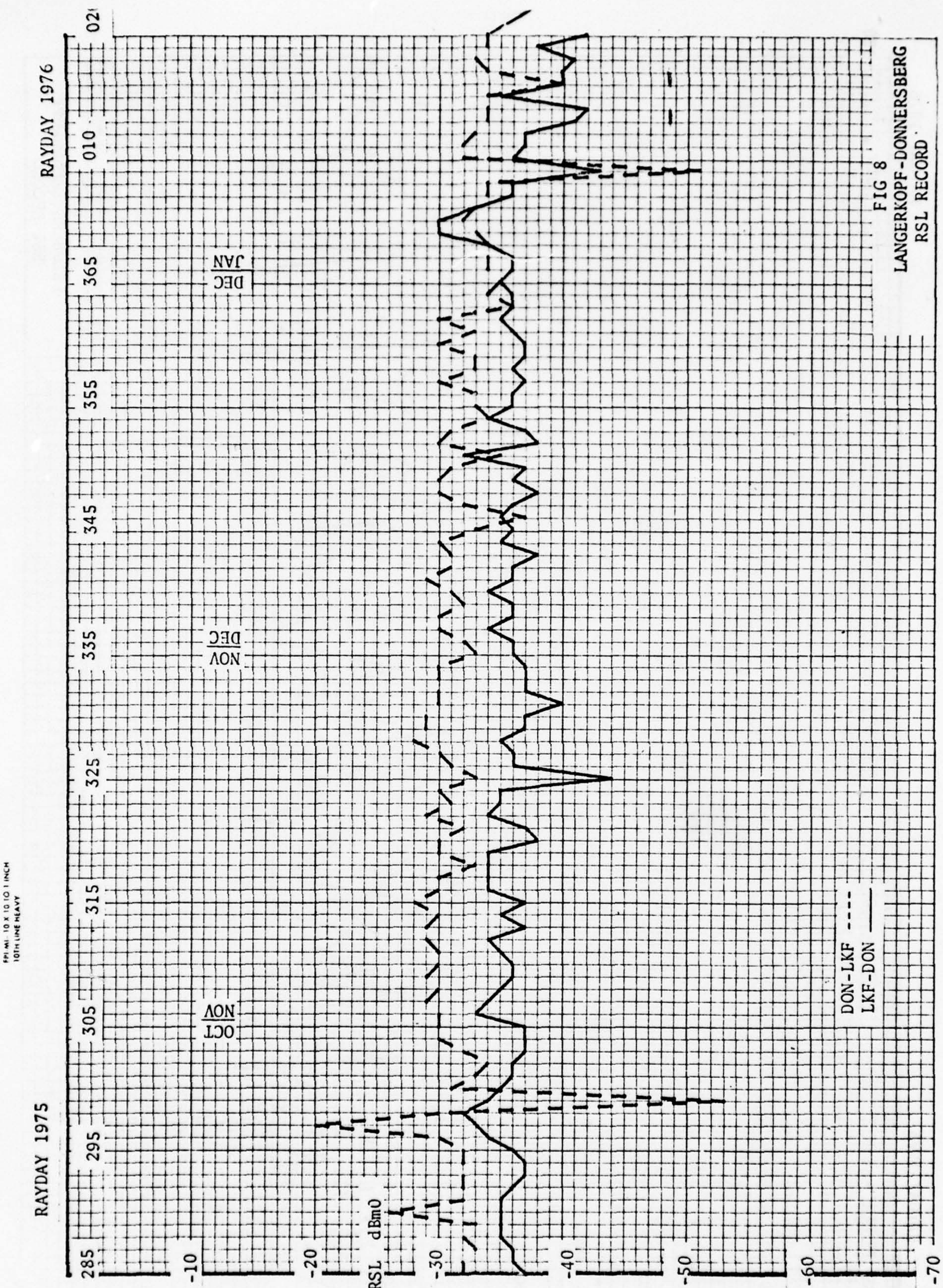


FIG 8
LANGERKOPF-DONNERSBERG
RSL RECORD

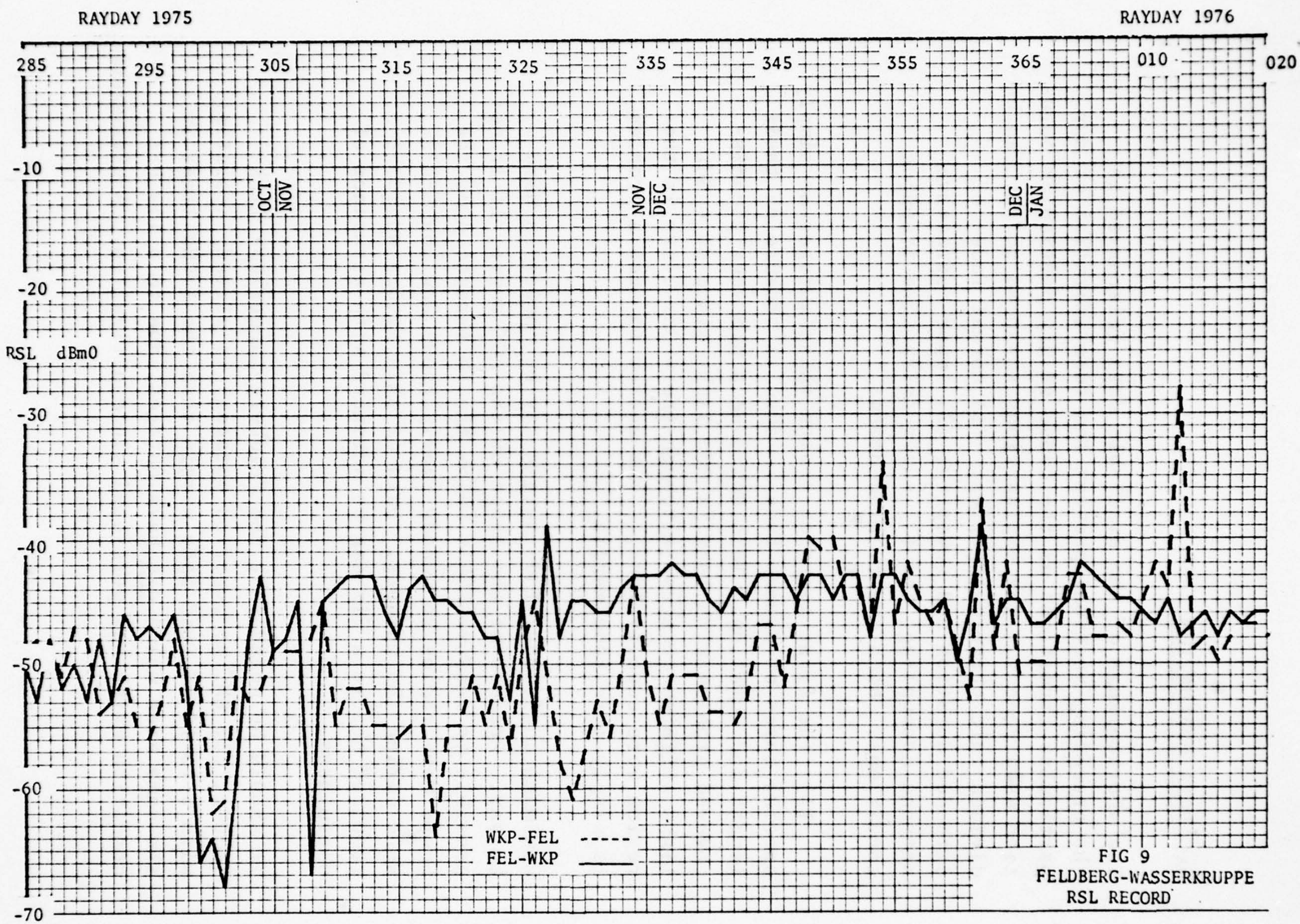


FIG 9
FELDBERG-WASSERKRUPPE
RSL RECORD

5. DATA EVALUATION

The shortcomings of the available data (discussed in the preceding section) prevent the identification of any particular conditions as the cause or any particular solution as a remedy. The explanations advanced so far can be divided into three categories: (1) normal fades of extended duration and severity; (2) super-refractive antenna decoupling, and (3) super-refractive trapping conditions. Each are treated below:

(1) The first approach treats these outages as simply special cases of common fades - special because of their length and duration. This could be a previously undiscovered problem with long, 8 GHz links since no 4 GHz links suffered outages (although the 4 GHz links in the region were equally long). The answer to such a problem is simply more fade margin.

How much additional fade margin may be needed is hard to say. Because of the shape of the AGC curve, it is not possible to measure RSL's below the FM threshold of the Scope Comm radios so nobody really knows how low RSL's were during the outages. Data of this nature would be required before a fix can be advanced with assurance of usefulness.

It should be noted that the Feldberg-Langerkopf link (4 GHz, 115 KM, no reported outages) is already operating with 5 to 10 dB less fade margin than the 8 GHz links in the same area which did have outages, due to a low RSL condition which has persisted since activation. A phenomena

which would affect 8 GHz so much more than 4 GHz is hard to imagine. Some have suggested smog or airborne particulate matter (perhaps partially ionized), but the geographic extent of the problem seems to argue against this.

(2) The second possible explanation is that the large, narrow beamwidth Scope Comm antennas were subjected to a refractive decoupling effect. This occurs when the refractive index gradient along a particular path changes enough from "normal" conditions to cause the received signal to arrive at an unusual angle - perhaps even outside the beam of the receiving antenna. The narrower beamwidth antennas are used on the 8 GHz links, so these are more susceptible than 4 GHz links.

This can be expressed quantitatively as:[4]

$$\beta = 2.86 \times 10^{-5} L \left(-40 - \frac{dN}{dh}\right)$$

where: β = the change in arrival angle (degrees).

L = the path length in kilometers.

$\frac{dN}{dh}$ = the new refractivity gradient (N-units/km).

Decoupling is most often associated with super-refraction, and moderate super-refraction was indicated by the radiosonde data. If the depressed RSL's on the Feldberg-Langerkopf link during the October outages are taken as indicative of being at the threshold of decoupling (i.e., signals arriving on the very edge of the beam), then the above equation indicates that the prevailing refractivity gradient was -205 N-units per kilometer. While this is

considerably more intense than the radiosonde data indicates, it is credible in light of the difficulties associated with the radiosonde. This gradient is sufficient to have caused decoupling on the Adenau-Feldberg, Feldberg-Schwarzenborn and Bonstetten-Hohenstadt links. However, the Donnersberg-Koenigstul, Muhl-Schoenfeld and Muhl-Langerkopf links would require gradients of -246, -237, and -260 N-units/km, respectively. This whole analysis assumes, of course, that all the antennas involved had optimal alignment under average (-40 N-units/km) conditions. A slight misalignment of an antenna - 0.1° or so - could radically change these figures while not affecting normal operation. The point is, however, that decoupling is a plausible explanation.

(3) The third theory advanced is that the transmitted signal was diverted away (trapped) from the vicinity of the receiving antenna by an extremely strong super-refractive ducting layer. This case is different from the second theory - where signal energy was available near the receiving antenna - by an arrangement of antenna heights and layer heights which prevented any signal from getting to the receiving antenna. The topography of the paths involved - a bowl-shaped (concave) profile, cut by a major river - is conducive to the formation of super-refractive trapping layers, and the static high pressure system would have sharply decreased the normal atmospheric turbulence necessary to dissipate these layers. The severity of the fades and their tendency to favor late evening and early morning hours supports this theory, but detailed weather information is needed to confirm this theory.

One additional significant effort was made at data analysis. A computer program was written and executed which cross-correlated the PMP RSL data for various links. Samples of these results are contained in Appendix C. These correlations utilized two to four months of PMP data and produced both interesting and disappointing results.

On the negative side, most links exhibited a non-reciprocal behavior. That is to say, RSL's taken on one end of the link were poorly correlated with values measured at the opposite end. Whether this is due to problems with the PMP data or the size of the sample is uncertain. If other data were available, a check on validity could be made.

On the other hand, RSL's on the Feldberg-Langerkopf link were found to have fairly good correlation with the Muhl-Langerkopf RSL's of the previous day - as one might expect since weather systems move regularly from west to east. A similar result holds for Feldberg-Langerkopf when compared against Muhl-Schoenfeld.

Perhaps the most interesting result is evident in the Muhl-Schoenfeld autocorrelation record. Here a definite cycle of about 21 days duration shows up as a peak at ± 21 days offset. There are a number of possible explanations for this, including periodic equipment maintenance, a statistically invalid data sample, or weather cycles. But compare this 21 day figure with the Table of Outages, Table 1. Use 25 October (an outage day) as a reference

point. Twenty-one days later is 15 November - not an outage day, but the 14th was. Another 21 days gives us 6 December, with no recorded outages. But, 21 days later is 27 December - one day before an outage period. Extrapolating into 1976, 7 February is indicated (four days before an outage) as well as 28 February (an outage day).

Is this periodicity significant? Could it be used in predicting outages? Why is it less prominent in the other RSL correlations - even of Muhl-Schoenfeld during December and January? Additional investigations are needed to answer these questions.

6. POSSIBLE SOLUTIONS

The solutions to the outage problem can only be identified when the cause is better understood. Increasing antenna size to improve fade margin would make the link more susceptible to decoupling and actually degrade performance if decoupling were really the cause. As a result, this section will only point out the types of solutions indicated by the three possible causes.

Fade margin can be obtained in several ways if that is the culprit. Larger antennas or reduced transmission line losses would have a double effect, being counted at each end of the link. More powerful transmitters could run into licensing problems and jumble the already crowded electrospace, but a more sensitive receiver would not affect any other installation (any may be as simple as an outboard preamp). Other equipment improvements may be possible.

If the problem is antenna decoupling, the solution will involve the antennas. Present antenna installations are not optimized to deal with decoupling conditions. An upward tilt of about .2° (costing 2dB in normal RSL) may solve the problem on some links with the side benefit of reduced reflection fading. The use of smaller antennas, with fade margin restored by some other means, could work on other links. A triple diversity system using a small, wide beam antenna for transmitting and receiving, and narrow beam receiving antennas (one tilted slightly up,

the other down) has been suggested. This would require additional tower space, waveguide runs and receivers as well as a different combiner but may be necessary in extreme cases. New antenna designs, having high gain but fairly wide vertical beamwidth, after the fashion of radar antennas, may be possible.

If trapping layers are the problem, the solution may involve re-locating antennas. Positioning receive and transmit dishes well above (taller towers may be needed) or below the offending layers should solve the problem. Diversity separations on the order of 50m or more could be dictated by this approach. The extreme case would be a two-path arrangement such as Houtem-Swingate.

The costliest solution - but one which should be effective against all three causes - is to make the links shorter by adding repeater sites. A procedural approach to the problem could be the provision of additional altroute capability or more effective altroute procedures, for priority circuits. This would be facilitated by a capability to predict outages, either from weather data or outages which have already occurred.

The best solution - by any criteria - can only be identified after the cause is more clearly understood. This requires data on RSL's and weather conditions more accurate and extensive than presently available. Until this is available, exact information on the solution and its cost cannot be advanced.

7. RECOMMENDATIONS

It is recommended that a multi-phased study, as outlined in Appendix B, be initiated. The purpose of this study would be to acquire data to be used in investigating the relationship between propagation and weather characteristics.

Radio performance data that is currently available is not adequate to confidently provide an engineering solution to the outage problem. To do this, it will be necessary to gather data of a much more extensive nature than the existing PMP data, as well as extensive weather data in the vicinity of the radio links under study.

The risk associated with studying a problem of this nature, i.e., a weather phenomenon, is that a similar weather condition may not reoccur any time soon. The Air Force has been involved in European microwave communications for many years, however centralized reporting and monitoring of outages is a recent inovation. Consequently long term records are not available to indicate the frequency with which this type of outage occurs. This poses problems in predetermining the length of time that data should be taken to assure that an outage period has been recorded. Three or four months of data taken in the fall of any year may be adequate; on the other hand, several years of continuous data may be required. Due to the nature of the problem, the gathering of data does not guarantee that a reasonable solution can be found. The alternatives to further study are either finding a solution

by trial and error or accepting the outages as unavoidable.

The study should be multi-phased to permit evaluation of the data and re-orientation of the project if indicated at some preplanned review point. A substantial cost savings may be realized if the results of the early phases indicate that later phases are unnecessary or impractical.

The results expected to come from such a study (condensed from Appendix B) are the following:

a. The conditions that prevailed near the affected sites prior to, during, and after the outage.

b. If a microwave path exists from the vicinity of the transmitter to the vicinity of the receiver at the time of the outage.

c. The descriptive statistics of received signal parameters on the affected links.

d. The correlation between measured atmospheric conditions and signal parameters.

e. Generalization of the above results.

Appendix B should be consulted for a detailed discussion.

The short term objective of the study would be improvements in the reliability of the DCS in Germany. The results may also be applicable worldwide to increase the reliability of systems to be engineered in the future.

References

1. AFCS Pamphlet 100-35, Systems Approach to Wideband Communications, September 1970.

2. Rome Air Development Center Report No RADC-TR-74-330, Line of Sight Techniques Investigation, P.A. Bello, et al, January 1975.

3. Engineering Consideration for Microwave Communications System, references from W.T. Barnett, Lenkurt Electric Co, 1975.

4. Institute for Telecommunication Sciences Report OT TM-116, Performance Estimates for Scope Communications System, Subsystem 3, October 1972.

5. Institute for Telecommunication Sciences Report RLTM-ITS 116, Survey of the Possibility of Short-Range Radio Predictions from Meteorological Data, February 1968.

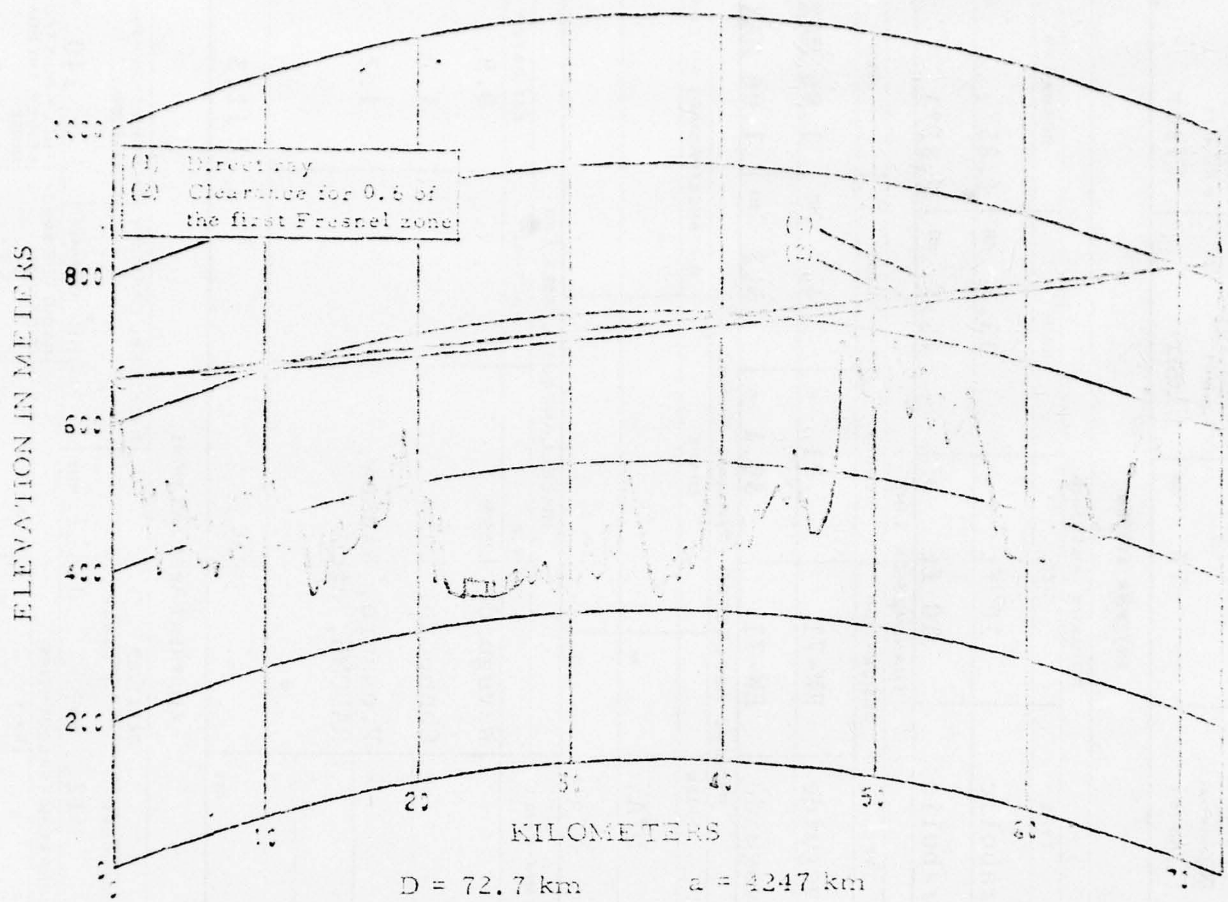
6. National Bureau of Standards Technical Note 99, A Survey of the Techniques for Measuring the Radio Refractive Index, R.E. McGavin, May 1962.

Acknowledgements

Grateful appreciation is expressed to Capt James W. Goldey, AFCS Staff Weather Officer, and Capt William E. Holtkamp of the AFCS Directorate of Systems Evaluation, for the data and technical comments which they have supplied. Mr. Gary Heckman of the 1842 EEG, Wideband Radio Systems Section is thanked for his assistance with the computer programs.

APPENDIX A

RSL DISTRIBUTIONS/PATH PROFILES



D = 72.7 km a = 4247 km

h_1 = 61.0 m k = 0.667 $\frac{\Delta N}{\Delta h}$ = + 78.5 N-units/km h_2 = 70.1 m

Langerkopf-Muhl terrain profile.

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DATA SHEET

B-1: LOS SYSTEM PARAMETERS

SITE NO. 1 (Tx)	DATE
LANGERKOPF	14 Apr 76
SITE NO. 2 (Rx)	**LINK NO.**
MUHL	M0069

PATH PARAMETERS

TYPE CLIMATE	TYPE TERRAIN	PATH LENGTH	PATH CLEARANCE (Minimum): FRESNEL ZONES (@ K = 2/3)	PATH CLEARANCE (Minimum): FRESNEL ZONES (@ K = 4/3)
[XX] HUMID [ ] NORMAL [ ] DRY	[ ] SMOOTH [XX] NORMAL [ ] ROUGH	73 km	Clear	Clear

ANTENNA SYSTEM

PRIMARY ANTENNA

	TYPE	SIZE	GAIN	BEAMWIDTH
DISTANT Tx	Parabolic	10 ft m	45.5 dB	(.85°) rad
LOCAL Rx	Parabolic	10 ft m	45.5 dB	(.85°) rad

TRANSMISSION LINE

	TYPE	DESIGNATION	LENGTH	LOSS	VSWR
DISTANT Tx	Waveguide	EW-71	71 m	4.7 dB	1.06 MAX
LOCAL Rx	Waveguide	EW-71	80.1 m	5.2 dB	1.06 MAX

PASSIVE REFLECTOR (Periscope System)

	SIZE	SHAPE	DISTANCE/PRIMARY ANTENNA
DISTANT Tx	N/A m		m
LOCAL Rx	N/A m		m

PASSIVE REFLECTOR (Mid-Path)

SIZE		m
DISTANCE FROM	Tx	m
DISTANCE FROM	Rx	m
INCLUDED HORIZONTAL ANGLE		deg

MISCELLANEOUS LOSSES (dB)

SOURCE	ACTUAL	ESTIMATED
Waveguide Loss		9.9
Connector Loss		1.2
Pressure, Window, RADOME, etc.		1.2
TOTAL		12.3

EQUIPMENT SPECIFICATIONS

TRANSMITTER POWER	RECEIVER: NOISE FIGURE	RECEIVER: IF BANDWIDTH	RADIO CHNL CAPACITY	FM DEVIATION (Per Channel RMS)
37 dBm	12 dB	20.422 MHz	600 Channels	140 KHz

OPERATING FREQUENCIES: TX 1	TX 2	RX 1	RX 2	RADIO NPR SPECIFICATION	FULLY QUIETED RECEIVER THERMAL NOISE
8 GHz	GHz	8 GHz	GHz	55 dB	10 pWCO

BASEBAND FREQUENCIES: LOWER	HIGHER	PRE-EMPHASIS: AVAL	TOP CHNL GAIN	MULTIPLEX NOISE SPECIFICATION: LOADED	UNLOADED
60 KHz	2540 KHz	[XX] YES [ ] NO	dB	22 dBrnCO	21 dBrnCO

DIVERSITY CONFIGURATION

DIVERSITY: ORDER	TYPE	SEPARATION (If applicable): FREQUENCY	ANTENNA	TYPE COMBINER
Dual	Space	N/A GHz	10 m	MAX/RATIO

AFCS FORM JUL 72 705 REPLACES AFCS FORMS 514 & 514A, MAY 69, WHICH ARE OBSOLETE.

ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
21b	Frequency Separation	N/A	GHz	Link Specifications
21c	Frequency Diversity Improvement	N/A		Item 21a x $\frac{\text{(Item 21b)}}{\text{(Item 3)}}$ x antilog $\left[\frac{\text{Item 17}}{10}\right]$
22a	Antenna Separation	10	m	Link Specifications
22b	Space Diversity Improvement	* 612		1.2×10^{-3} x Item 3 x $(\text{Item 22a})^2$ x antilog $\left[\frac{\text{Item 17}}{10}\right]$/ Item 4 SEE NOTE
23	Diversity Outage Probability	0.0000037		Item 20/Item 21c or Item 20/Item 22b
24	Radio Channel Capacity	** 600		Manufacturer's Specifications
25	Per Channel RMS Deviation	** 140	KHz	Link Specifications
26	Load Factor	** 17.78	dBmO	See text and Figure 3-2
27	Load Factor	7.74		Antilog $\left[\frac{\text{Item 26}}{20}\right]$
28	Peak Deviation	4832	KHz	Item 25 x Item 27 x 4.46
29	Highest Modulating Frequency	** 2540	KHz	See text and Figure 3-3
30	Modulation Index	1.9		Item 28/Item 29
31	Required IF Bandwidth	19.824	MHz	10^{-3} x (2 x Item 28 + 4 x Item 29) *(NOTE: Bandwidth of Item 11 must exceed this.)*
32	Diversity Improvement Factor	** 3	dB	Figure 3-4 for type combiner used
33	FM Improvement Factor	-25.2	dB	20 log (Item 25/Item 29)
34	Correction Factor for Voice Channel Bandwidth	38.2	dB	10 log (Item 11/3.1) + 30
35	Pre-emphasis Improvement	** 4	dB	Manufacturer's Specifications
36a	Channel Signal-to-Noise Ratio, Front-End Noise Only	76.8	dB	Item 15 + Item 32 + Item 33 + Item 34 + Item 35
36b	Channel Thermal Noise, Front-End Only	11.7	dBrnCO	88.5 – Item 36a
36c	Channel Thermal Noise, Front-End Only	14.8	pWCO	Antilog $\left[\frac{\text{Item 36b}}{10}\right]$
37	Noise Power Ratio	** 55	dB	Manufacturer's Specifications
38	Baseband Width	** 2480	KHz	Link Specifications or Figure 3-3
39a	Channel Signal-to-Noise Ratio, Idle and Intermodulation Noise Only	66.8	dB	Item 37 + 10 log (Item 38/3.1) – Item 26
39b	Channel Noise, Radio Equipment Only	21.7	dBrnCO	88.5 – Item 39a
39c	Channel Noise, Radio Equipment Only	148	pWCO	Antilog $\left[\frac{\text{Item 39b}}{10}\right]$
40	Fully Quieted Receiver Thermal Noise	10	pWCO	See Text
41a	Total Transmission Media Noise, Per Channel	162.8	pWCO	Item 36c + Item 39c

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DATA SHEET	SITE NO. 1 (Tx)	DATE
B-2: LOS PATH CALCULATIONS *(CONTINUATION)*	LANGERKOPF	14 Apr 76
	SITE NO. 2 (Rx)	LINK NO.
	MUHL	MØØ69

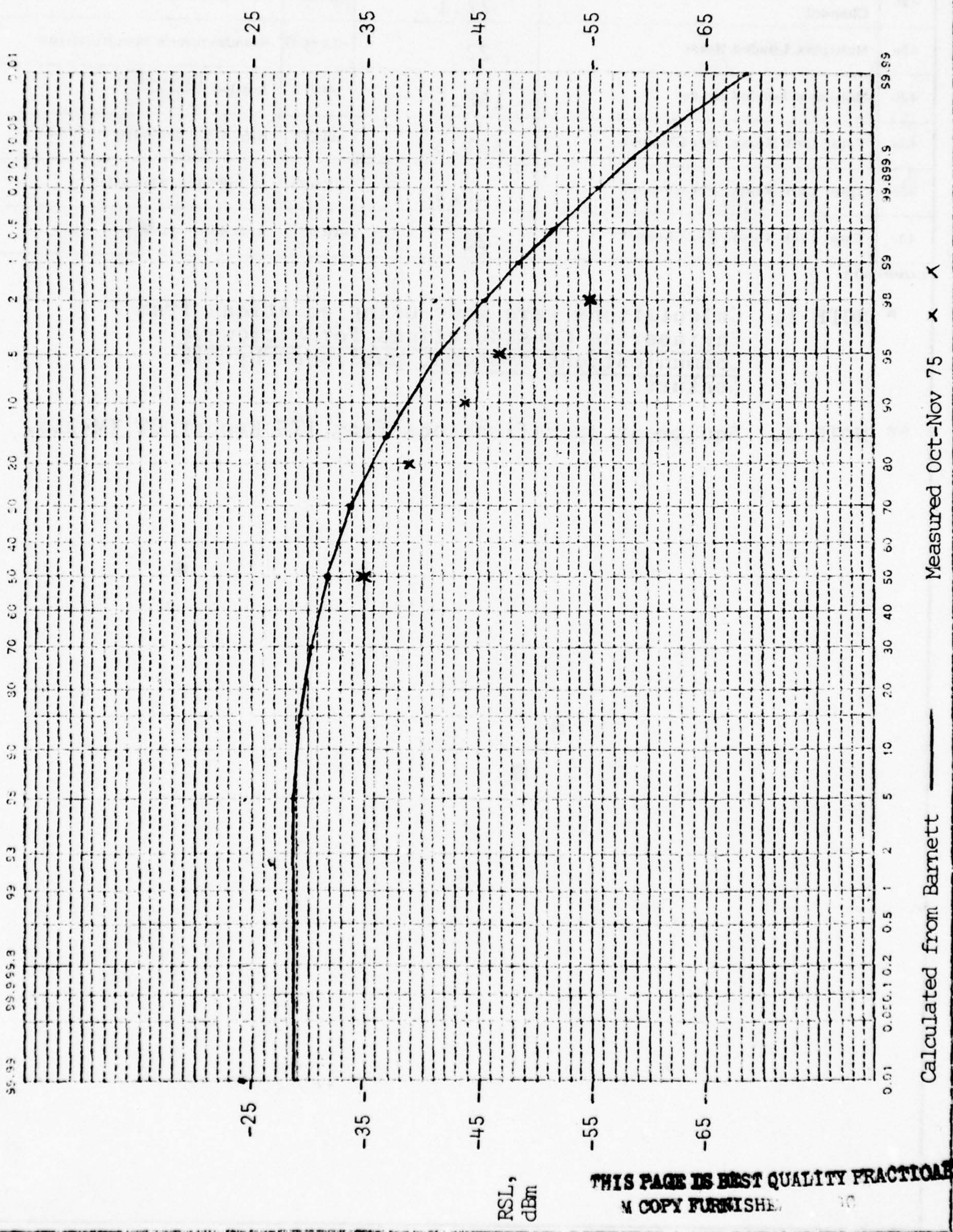
ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
41b	Total Transmission Media Noise, Per Channel	22.1	dBrnCO	10 log (Item 41a)
42a	Multiplex Loaded Noise	22	dBrnCO	Manufacturer's Specifications
42b	Multiplex Loaded Noise	158.5	pWCO	Antilog $\left[\frac{\text{Item 42a}}{10}\right]$
43a	Total Link Noise, Per Channel	321.3	pWCO	Item 41a + Item 42b
43b	Total Link Noise, Per Channel	26.5	dBrnO	10 log (Item 43a) + 1.5
43c	Total Link Noise, Per Channel	25	dBrnCO	Item 43b − 1.5

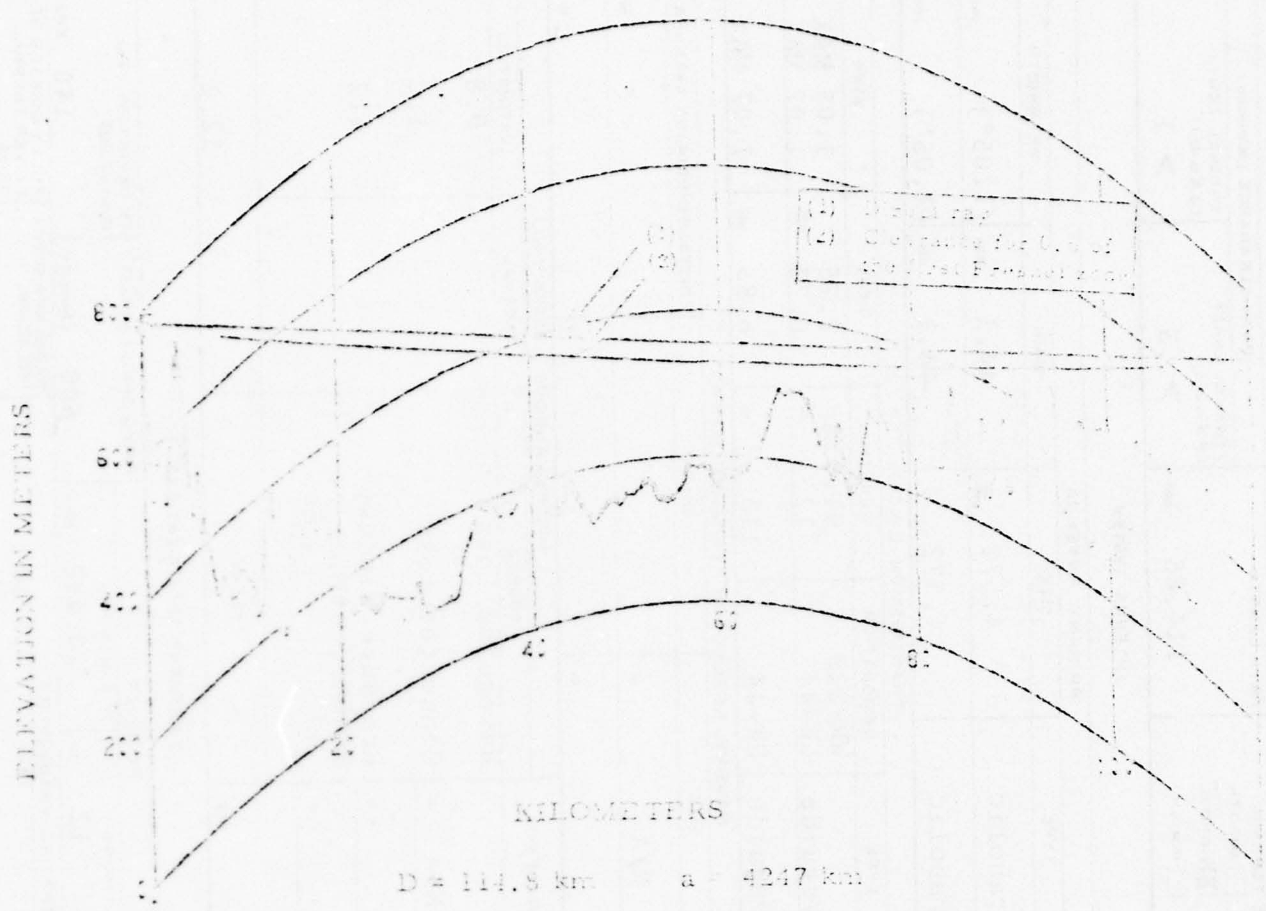
COMMENTS

* NOTE 1. Calculations were made using equations from <u>Engineering Considerations for Microwave Communications Systems</u>, published by GTE Lenkurt.

** NOTE 2. Equipment specifications from ITS Report OT TM-116.

DATA SHEET	FACILITY TESTED	DATE
A-6: PROBABILITY GRID	MUHL	
	DISTANT FACILITY	INITIALS
	LANGERKOPF	
TITLE	REFERENCE	
RSL DISTRIBUTION (SINGLE RECEIVER)	73 km., 8 GHz.	





$D = 114.8$ km $a = 4247$ km

$h_1 = 93.4$ m $k = 0.667$ $\frac{\Delta N}{\Delta h} = +78.5$ N-units/km $h_2 = 163.0$ m

Feldberg-Langerkopf terrain profile.

A-7

DATA SHEET	SITE NO. 1 *(Tx)*	DATE
B-1: LOS SYSTEM PARAMETERS	FELDBERG	14 Apr 76
	SITE NO. 2 *(Rx)*	LINK NO.
	LANGERKOPF	MØØ63

PATH PARAMETERS

TYPE CLIMATE	TYPE TERRAIN	PATH LENGTH	PATH CLEARANCE *(Minimum)* FRESNEL ZONES *(@ K = 2/3)*	FRESNEL ZONES *(@ K = 4/3)*
[XX] HUMID [ ] NORMAL [ ] DRY	[ ] SMOOTH [XX] NORMAL [ ] ROUGH	114.85 km	> .3	> 1

ANTENNA SYSTEM

PRIMARY ANTENNA

	TYPE	SIZE	GAIN	BEAMWIDTH
DISTANT TX	Parabolic	4.572 m	44.1 dB	(1.05°) rad
LOCAL RX	Parabolic	4.572 m	44.1 dB	(1.05°) rad

TRANSMISSION LINE

	TYPE	DESIGNATION	LENGTH	LOSS	VSWR
DISTANT TX	Waveguide	WR-229 EW-44	91.4 m 12 m	2.25 0.73 dB	1.05 MAX 1.07 MAX
LOCAL RX	Waveguide	EW-44	113 m	6.85 dB	1.07 MAX

PASSIVE REFLECTOR *(Periscope System)*

	SIZE	SHAPE	DISTANCE/PRIMARY ANTENNA
DISTANT TX	N/A m		m
LOCAL RX	m		m

PASSIVE REFLECTOR *(Mid-Path)*

SIZE		N/A m
DISTANCE FROM	Tx	m
	Rx	m
INCLUDED HORIZONTAL ANGLE		deg

MISCELLANEOUS LOSSES *(dB)*

SOURCE	ACTUAL	ESTIMATED
Waveguide Loss		9.8
Connector Loss		1.2
Pressure Window, RADOME, etc.		1.2
TOTAL		12.2

EQUIPMENT SPECIFICATIONS

TRANSMITTER POWER	RECEIVER NOISE FIGURE	RECEIVER IF BANDWIDTH	RADIO CHNL CAPACITY	FM DEVIATION *(Per Channel RMS)*
37 dBm	12 dB	20.422 MHz	600 Channels	140 KHz

OPERATING FREQUENCIES TX 1	TX 2	RX 1	RX 2	RADIO NPR SPECIFICATION	FULLY QUIETED RECEIVER THERMAL NOISE
4.5 GHz	GHz	4.5 GHz	GHz	55 dB	10 pWCO

BASEBAND FREQUENCIES LOWER	HIGHER	PRE-EMPHASIS AVAL	TOP CHNL GAIN	MULTIPLEX NOISE SPECIFICATION LOADED	UNLOADED
60 KHz	2540 KHz	[XX] YES [ ] NO	dB	22 dBrnCO	21 dBrnCO

DIVERSITY CONFIGURATION

DIVERSITY ORDER	TYPE	SEPARATION *(If applicable)* FREQUENCY	ANTENNA	TYPE COMBINER
Dual	Space	N/A GHz	10 m	MAX GAIN

AFCS FORM JUL 72 705 — REPLACES AFCS FORMS 514 & 514A, MAY 69, WHICH ARE OBSOLETE.

DATA SHEET	SITE NO. 1 (Tx)	DATE
B-2: LOS PATH CALCULATIONS	FELDBERG	14 Apr 76
	SITE NO. 2 (Rx)	LINK NO.
	LANGERKOPF	MØØ63

ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
1	Transmitter Power	** 37	dBm	Manufacturer's Specifications
2a	Primary Antenna Gain	** 88.2	dB	Manufacturer's Specifications
2b	Passive Reflector Gain	N/A	dB	See Attachment 2
2c	Total Antenna Gain	88.2	dB	Item 2a + Item 2b
3	Operating Frequency *(Mean)*	4.5	GHz	Link Specifications
4	Path Length	115	km	From Path Profile
5	Basic Transmission Loss	146.8	dB	20 log (Item 3) + 20 log (Item 4) + 92.5
6	Obstruction Loss @ K = 4/3	0	dB	See Figure 3-1
7	Obstruction Loss @ K = 2/3	0	dB	See Figure 3-1
8	Line and Miscellaneous Losses	12.2	dB	Manufacturer's Specifications
9a	Median Received Signal Level *(Single Receiver)*, K = 4/3	-33.8	dBm	Item 1 + Item 2c – Item 5 – Item 6 – Item 8
9b	Faded Median Received Signal Level *(Single Receiver)*, K = 2/3	-33.8	dBm	Item 1 + Item 2c – Item 5 – Item 7 – Item 8
10	Thermal Noise per Hz of Bandwidth	– 174	dBm	For T = 290 deg K
11	Receiver IF Bandwidth	** 20.422	MHz	Manufacturer's Specifications
12	IF Bandwidth in dB	73.1	dB	60 + 10 log (Item 11)
13	Receiver Noise Figure	** 12	dB	Manufacturer's Specifications
14	Receiver Noise Threshold	-88.9	dBm	Item 10 + Item 12 + Item 13
15	Median Carrier-to-Noise Ratio	55.1	dB	Item 9a – Item 14
16	Receiver FM Threshold	-78.9	dBm	10 + Item 14
17	Fade Margin	45.1	dB	Item 9a – Item 16 + Item 6 – Item 7
18	Climate Factor	1/2		Humid = 1/2 Normal = 1/4 Dry = 1/8
19	Terrain Factor	1		Smooth = 4 Normal = 1 Rough = 1/4
20	Single Receiver Outage Probability	* 0.00321	%	$5.1 \times 10^{-7} \times$ Item 18 $\times$ Item 19 $\times$ (Item 3)$^{1.5}$ $\times$ (Item 4)^{3} $\times$ Antilog $\left[\frac{-\text{Item 17}}{10}\right]$ SEE NOTE 1
21a	Factor for Frequency Diversity Improvement	N/A		Freq = 4 GHz, 1/2 Freq = 8 GHz, 1/8 Freq = 12 GHz, 1/12

ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
21b	Frequency Separation	N/A	GHz	Link Specifications
21c	Frequency Diversity Improvement	N/A		Item 21a x $\frac{\text{(Item 21b)}}{\text{(Item 3)}}$ x antilog $\left[\frac{\text{Item 17}}{10}\right]$
22a	Antenna Separation	10	m	Link Specifications
22b	Space Diversity Improvement	* 153		1.2 x 10^{-3} x Item 3 x (Item 22a)^2 x antilog $\left[\frac{\text{Item 17}}{10}\right]$/ Item 4 SEE NOTE 1
23	Diversity Outage Probability	0.000021		Item 20/Item 21c or Item 20/Item 22b
24	Radio Channel Capacity	** 600		Manufacturer's Specifications
25	Per Channel RMS Deviation	** 140	KHz	Link Specifications
26	Load Factor	** 17.78	dBmO	See text and Figure 3-2
27	Load Factor	7.74		Antilog $\left[\frac{\text{Item 26}}{20}\right]$
28	Peak Deviation	4832	KHz	Item 25 x Item 27 x 4.46
29	Highest Modulating Frequency	** 2540	KHz	See text and Figure 3-3
30	Modulation Index	1.9		Item 28/Item 29
31	Required IF Bandwidth	19.824	MHz	10^{-3} x (2 x Item 28 + 4 x Item 29) (*NOTE: Bandwidth of Item 11 must exceed this.*)
32	Diversity Improvement Factor	** 3	dB	Figure 3-4 for type combiner used
33	FM Improvement Factor	-25.2	dB	20 log (Item 25/Item 29)
34	Correction Factor for Voice Channel Bandwidth	38.2	dB	10 log (Item 11/3.1) + 30
35	Pre-emphasis Improvement	** 4	dB	Manufacturer's Specifications
36a	Channel Signal-to-Noise Ratio, Front-End Noise Only	75.1	dB	Item 15 + Item 32 + Item 33 + Item 34 + Item 35
36b	Channel Thermal Noise, Front-End Only	13.4	dBrnCO	88.5 – Item 36a
36c	Channel Thermal Noise, Front-End Only	21.8	pWCO	Antilog $\left[\frac{\text{Item 36b}}{10}\right]$
37	Noise Power Ratio	** 55	dB	Manufacturer's Specifications
38	Baseband Width	** 2480	KHz	Link Specifications or Figure 3-3
39a	Channel Signal-to-Noise Ratio, Idle and Intermodulation Noise Only	66.2	dB	Item 37 + 10 log (Item 38/3.1) – Item 26
39b	Channel Noise, Radio Equipment Only	22.3	dBrnCO	88.5 – Item 39a
39c	Channel Noise, Radio Equipment Only	169.8	pWCO	Antilog $\left[\frac{\text{Item 39b}}{10}\right]$
40	Fully Quieted Receiver Thermal Noise	10	pWCO	See Text
41a	Total Transmission Media Noise, Per Channel	191.6	pWCO	Item 36c + Item 39c

DATA SHEET **B-2: LOS PATH CALCULATIONS** *(CONTINUATION)*	SITE NO. 1 (Tx) FELDBERG SITE NO. 2 (Rx) LANGERKOPF	DATE 14 Apr 76 LINK NO. MØØ63

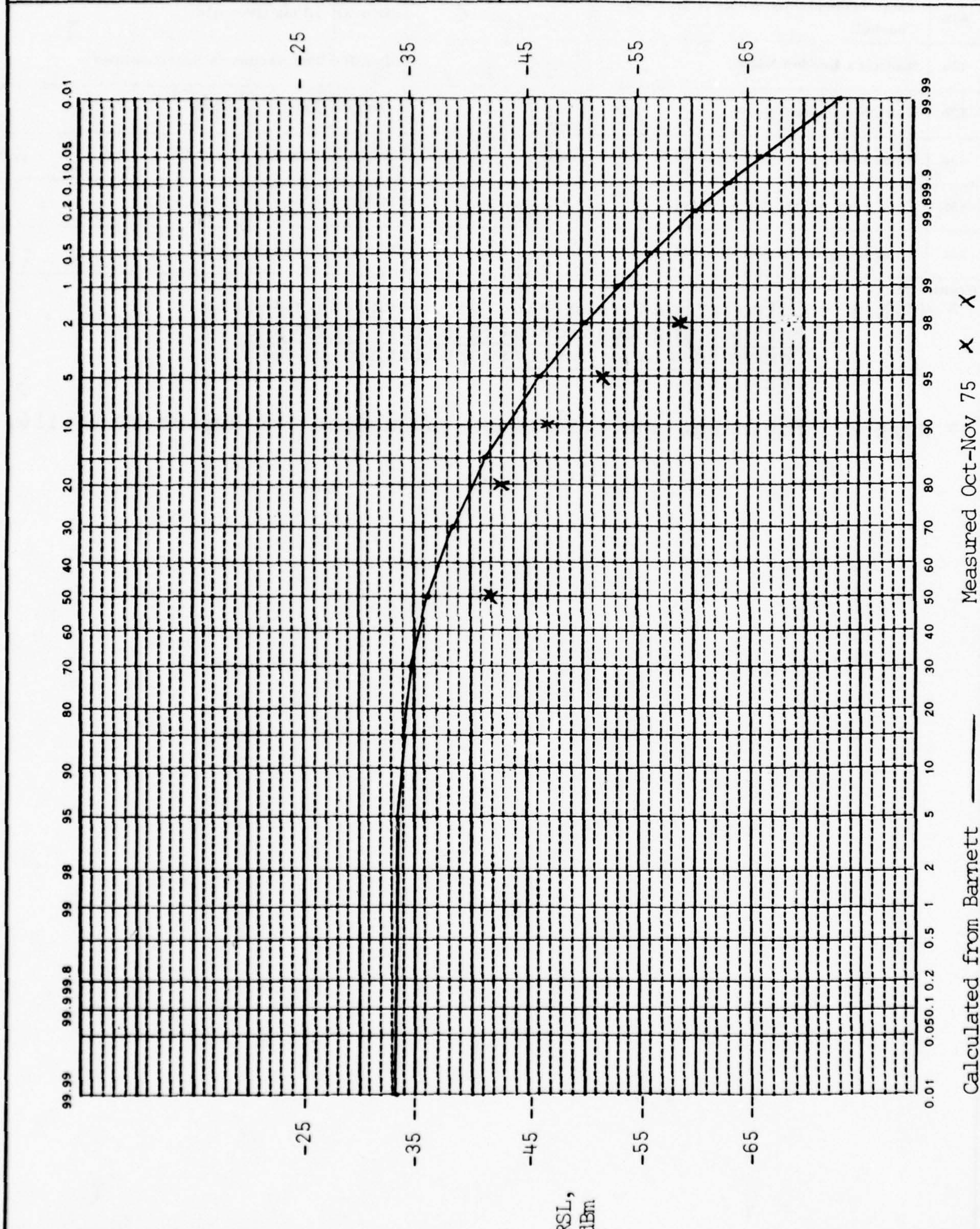
ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
41b	Total Transmission Media Noise, Per Channel	22.8	dBrnCO	10 log (Item 41a)
42a	Multiplex Loaded Noise	22	dBrnCO	Manufacturer's Specifications
42b	Multiplex Loaded Noise	158	pWCO	Antilog $\left[\frac{\text{Item 42a}}{10}\right]$
43a	Total Link Noise, Per Channel	350	pWCO	Item 41a + Item 42b
43b	Total Link Noise, Per Channel	26.9	dBrnO	10 log (Item 43a) + 1.5
43c	Total Link Noise, Per Channel	25.4	dBrnCO	Item 43b − 1.5

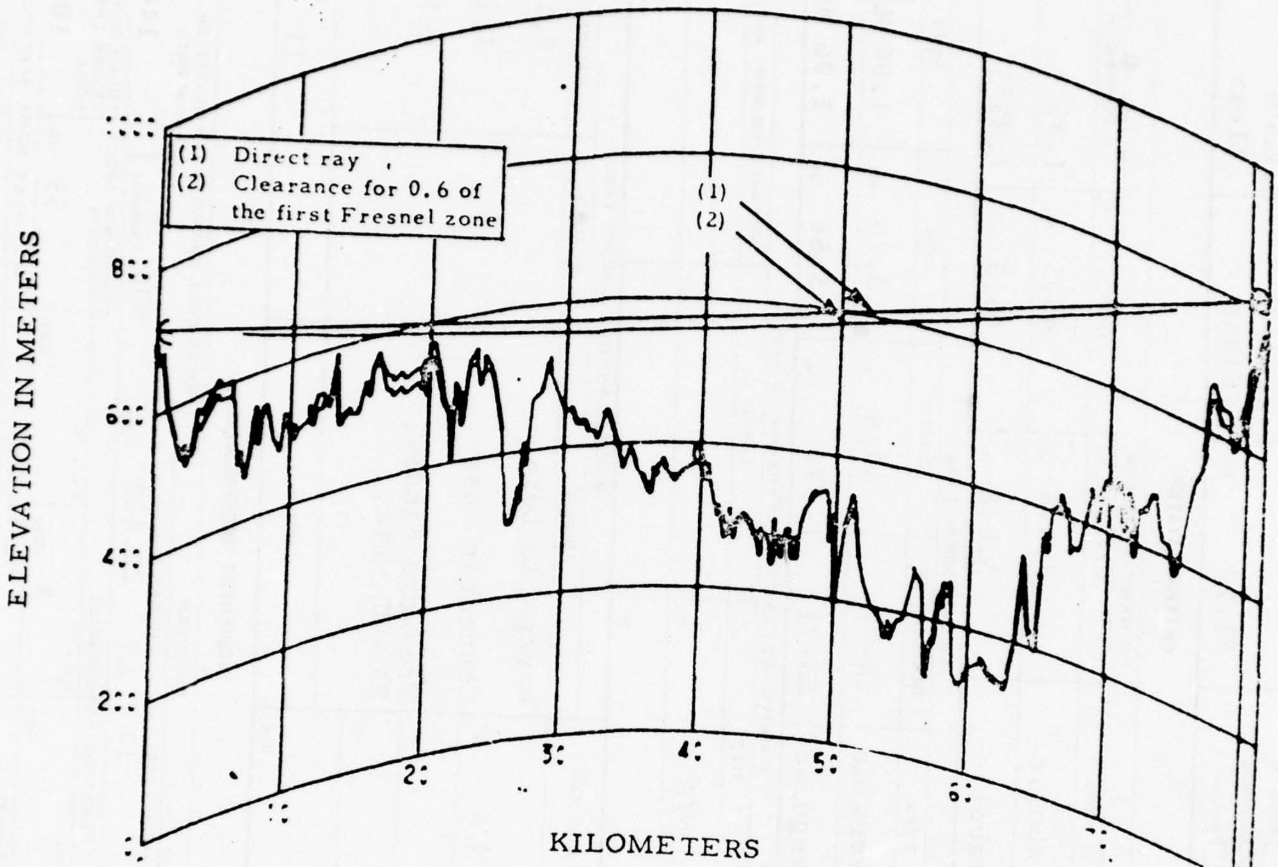
COMMENTS

* NOTE 1. Calculations were made using equations from Engineering Considerations for Microwave Communications Systems, published by GTE Lenkurt.

** NOTE 2. Equipment specifications taken from ITS Report OT TM-116.

DATA SHEET	FACILITY TESTED	DATE
A-6: PROBABILITY GRID	FELDBERG	
	DISTANT FACILITY	INITIALS
	LANGERKOPF	
TITLE	REFERENCE	
RSL DISTRIBUTION (SINGLE RECEIVER)	115 km., 4.5GHz	





D = 81.2 km   a = 4247 km

$h_1 = 39.6$ m $k = 0.667$ $\frac{\Delta N}{\Delta h} = +78.5$ N-units/km $h_2 = 64.0$ m

Schoenfeld-Muhl terrain profile.

DATA SHEET

B-1: LOS SYSTEM PARAMETERS

SITE NO. 1 (Tx)	DATE
SCHOENFELD	8 Apr 76
SITE NO. 2 (Rx)	**LINK NO.**
MUHL	MØØ67

PATH PARAMETERS

TYPE CLIMATE	TYPE TERRAIN	PATH LENGTH	PATH CLEARANCE (Minimum) FRESNEL ZONES (@ K = 2/3)	PATH CLEARANCE (Minimum) FRESNEL ZONES (@ K = 4/3)
[XX] HUMID [ ] NORMAL [ ] DRY	[ ] SMOOTH [XX] NORMAL [ ] ROUGH	81.23 km	Clear	Clear

ANTENNA SYSTEM

PRIMARY ANTENNA

	TYPE	SIZE	GAIN	BEAMWIDTH
DISTANT TX	Parabolic	3.048 m	45.5 dB	(.85°) rad
LOCAL RX	Parabolic	3.048 m	45.5 dB	(.85°) rad

TRANSMISSION LINE

	TYPE	DESIGNATION	LENGTH	LOSS	VSWR
DISTANT TX	Waveguide	EW-71	49.6 m	3.26 dB	1.06 MAX
LOCAL RX	Waveguide	EW-71	74 m	5.86 dB	1.06 MAX

PASSIVE REFLECTOR (Periscope System)

	SIZE	SHAPE	DISTANCE/PRIMARY ANTENNA
DISTANT TX	N/A m		m
LOCAL RX	m		m

PASSIVE REFLECTOR (Mid-Path)

SIZE		N/A m
DISTANCE FROM	Tx	m
DISTANCE FROM	Rx	m
INCLUDED HORIZONTAL ANGLE		deg

MISCELLANEOUS LOSSES (dB)

SOURCE	ACTUAL	ESTIMATED
Waveguide Loss		9.1
Connector Loss		1.2
Pressure Window, RADOME, etc.		0.7
TOTAL		11

EQUIPMENT SPECIFICATIONS

TRANSMITTER POWER	RECEIVER NOISE FIGURE	RECEIVER IF BANDWIDTH	RADIO CHNL CAPACITY	FM DEVIATION (Per Channel RMS)
37 dBm	12 dB	20.422 MHz	600 Channels	140 KHz

OPERATING FREQUENCIES TX 1	TX 2	RX 1	RX 2	RADIO NPR SPECIFICATION	FULLY QUIETED RECEIVER THERMAL NOISE
8 GHz	GHz	8 GHz	GHz	55 dB	10 pWCO

BASEBAND FREQUENCIES LOWER	HIGHER	PRE-EMPHASIS AVAL	TOP CHNL GAIN	MULTIPLEX NOISE SPECIFICATION LOADED	UNLOADED
60 KHz	2540 KHz	[XX] YES [ ] NO	dB	22 dBrnCO	21 dBrnCO

DIVERSITY CONFIGURATION

DIVERSITY ORDER	DIVERSITY TYPE	SEPARATION (If applicable) FREQUENCY	SEPARATION ANTENNA	TYPE COMBINER
Dual	Space	N/A GHz	10 m	MAX/RATIO

AFCS FORM JUL 72 705 REPLACES AFCS FORMS 514 & 514A, MAY 69, WHICH ARE OBSOLETE.

DATA SHEET	SITE NO. 1 (Tx)	DATE
B-2: LOS PATH CALCULATIONS	SCHOENFELD	8 Apr 76
	SITE NO. 2 (Rx)	LINK NO.
	MUHL	MØØ67

ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
1	Transmitter Power	** 37	dBm	Manufacturer's Specifications
2a	Primary Antenna Gain	** 91	dB	Manufacturer's Specifications
2b	Passive Reflector Gain	N/A	dB	See Attachment 2
2c	Total Antenna Gain	91	dB	Item 2a + Item 2b
3	Operating Frequency *(Mean)*	8	GHz	Link Specifications
4	Path Length	81.23	km	From Path Profile
5	Basic Transmission Loss	148.7	dB	20 log (Item 3) + 20 log (Item 4) + 92.5
6	Obstruction Loss @ K = 4/3	0	dB	See Figure 3-1
7	Obstruction Loss @ K = 2/3	0	dB	See Figure 3-1
8	Line and Miscellaneous Losses	11	dB	Manufacturer's Specifications
9a	Median Received Signal Level *(Single Receiver)*, K = 4/3	-31.7	dBm	Item 1 + Item 2c – Item 5 – Item 6 – Item 8
9b	Faded Median Received Signal Level *(Single Receiver)*, K = 2/3	-31.7	dBm	Item 1 + Item 2c – Item 5 – Item 7 – Item 8
10	Thermal Noise per Hz of Bandwidth	– 174	dBm	For T = 290 deg K
11	Receiver IF Bandwidth	** 20.422	MHz	Manufacturer's Specifications
12	IF Bandwidth in dB	73.1	dB	60 + 10 log (Item 11)
13	Receiver Noise Figure	12	dB	Manufacturer's Specifications
14	Receiver Noise Threshold	-88.9	dBm	Item 10 + Item 12 + Item 13
15	Median Carrier-to-Noise Ratio	57.2	dB	Item 9a – Item 14
16	Receiver FM Threshold	-78.9	dBm	10 + Item 14
17	Fade Margin	47.2	dB	Item 9a – Item 16 + Item 6 – Item 7
18	Climate Factor	1/2		Humid = 1/2 Normal = 1/4 Dry = 1/8
19	Terrain Factor	1		Smooth = 4 Normal = 1 Rough = 1/4
20	Single Receiver Outage Probability	* 0.00281	%	$5.1 \times 10^{-7} \times$ Item 18 $\times$ Item 19 $\times$ (Item 3)$^{1.5}$ $\times$ (Item 4)^{3} $\times$ Antilog $\left[\frac{-\text{Item 17}}{10}\right]$ SEE NOTE 1
21a	Factor for Frequency Diversity Improvement	N/A		Freq = 4 GHz, 1/2 Freq = 8 GHz, 1/8 Freq = 12 GHz, 1/12

ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
21b	Frequency Separation	N/A	GHz	Link Specifications
21c	Frequency Diversity Improvement	N/A		Item 21a x $\frac{\text{(Item 21b)}}{\text{(Item 3)}}$ x antilog $\left[\frac{\text{Item 17}}{10}\right]$
22a	Antenna Separation	10	m	Link Specifications
22b	Space Diversity Improvement	* 626		1.2×10^{-3} x Item 3 x (Item 22a)^2 x antilog $\left[\frac{\text{Item 17}}{10}\right]$/ Item 4 SEE NOTE 1
23	Diversity Outage Probability	0.0000045		Item 20/Item 21c or Item 20/Item 22b
24	Radio Channel Capacity	** 600		Manufacturer's Specifications
25	Per Channel RMS Deviation	** 140	KHz	Link Specifications
26	Load Factor	** 17.78	dBmO	See text and Figure 3-2
27	Load Factor	7.74		Antilog $\left[\frac{\text{Item 26}}{20}\right]$
28	Peak Deviation	4832.8	KHz	Item 25 x Item 27 x 4.46
29	Highest Modulating Frequency	** 2540	KHz	See text and Figure 3-3
30	Modulation Index	1.9		Item 28/Item 29
31	Required IF Bandwidth	19.825	MHz	10^{-3} x (2 x Item 28 + 4 x Item 29) *(NOTE: Bandwidth of Item 11 must exceed this.)*
32	Diversity Improvement Factor	** 3	dB	Figure 3-4 for type combiner used
33	FM Improvement Factor	-25.2	dB	20 log (Item 25/Item 29)
34	Correction Factor for Voice Channel Bandwidth	38.2	dB	10 log (Item 11/3.1) + 30
35	Pre-emphasis Improvement	** 4	dB	Manufacturer's Specifications
36a	Channel Signal-to-Noise Ratio, Front-End Noise Only	77.2	dB	Item 15 + Item 32 + Item 33 + Item 34 + Item 35
36b	Channel Thermal Noise, Front-End Only	11.3	dBrnCO	88.5 – Item 36a
36c	Channel Thermal Noise, Front-End Only	13.5	pWCO	Antilog $\left[\frac{\text{Item 36b}}{10}\right]$
37	Noise Power Ratio	** 55	dB	Manufacturer's Specifications
38	Baseband Width	** 2480	KHz	Link Specifications or Figure 3-3
39a	Channel Signal-to-Noise Ratio, Idle and Intermodulation Noise Only	66.25	dB	Item 37 + 10 log (Item 38/3.1) – Item 26
39b	Channel Noise, Radio Equipment Only	22.25	dBrnCO	88.5 – Item 39a
39c	Channel Noise, Radio Equipment Only	168	pWCO	Antilog $\left[\frac{\text{Item 39b}}{10}\right]$
40	Fully Quieted Receiver Thermal Noise	10	pWCO	See Text
41a	Total Transmission Media Noise, Per Channel	181.5	pWCO	Item 36c + Item 39c

DATA SHEET	SITE NO. 1 (Tx)	DATE
B-2: LOS PATH CALCULATIONS *(CONTINUATION)*	SCHOENFELD	8 Apr 76
	SITE NO. 2 (Rx)	LINK NO.
	MUHL	MØØ67

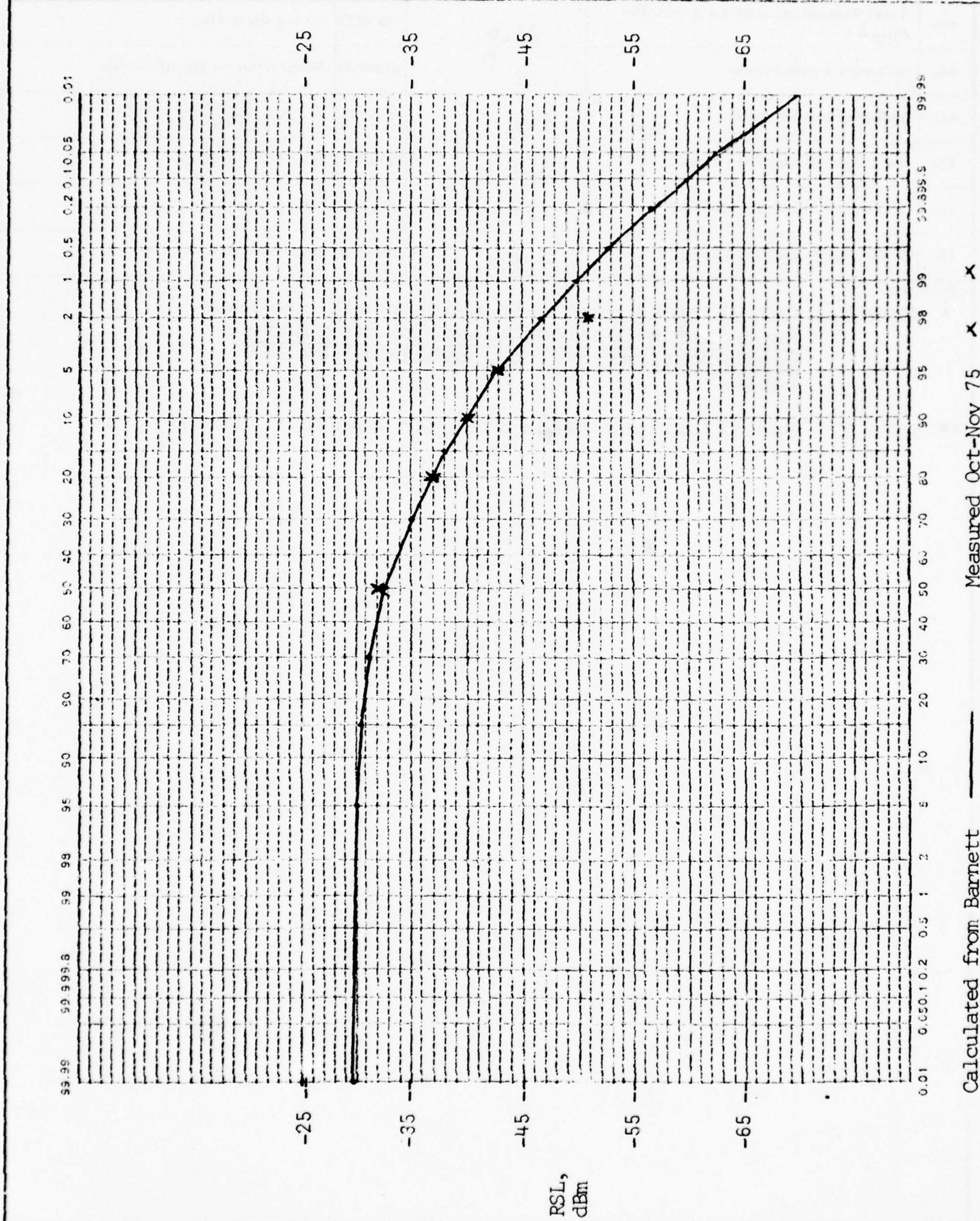
ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
41b	Total Transmission Media Noise, Per Channel	22.6	dBrnCO	10 log (Item 41a)
42a	Multiplex Loaded Noise	22	dBrnCO	Manufacturer's Specifications
42b	Multiplex Loaded Noise	158	pWCO	Antilog $\left[\frac{\text{Item 42a}}{10}\right]$
43a	Total Link Noise, Per Channel	339.5	pWCO	Item 41a + Item 42b
43b	Total Link Noise, Per Channel	27.3	dBrnO	10 log (Item 43a) + 1.5
43c	Total Link Noise, Per Channel	25.8	dBrnCO	Item 43b − 1.5

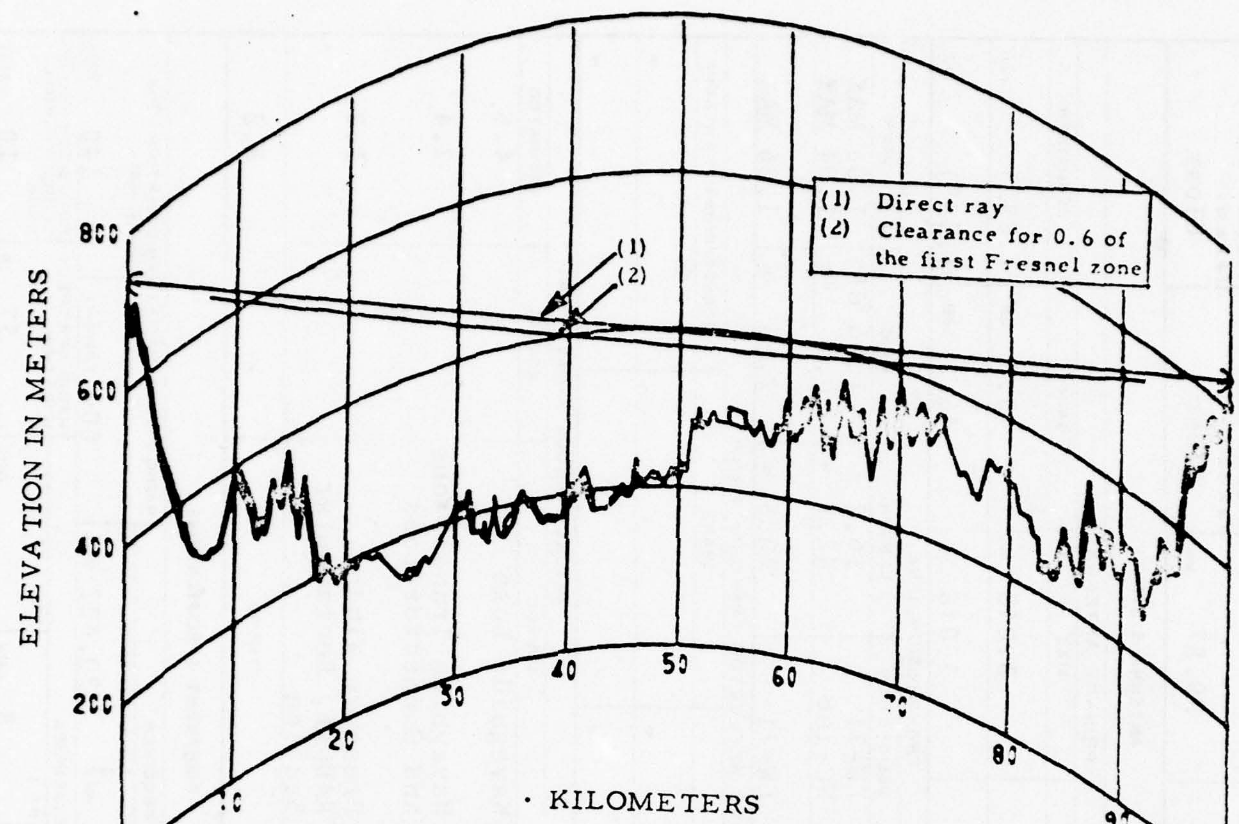
COMMENTS

* NOTE 1. Calculations were made using equations from <u>Engineering Considerations for Microwave Communications Systems</u>, published by GTE Lenkurt.

** NOTE 2. Specifications taken from ITS Report IT TM-116.

DATA SHEET	FACILITY TESTED	DATE
A-6: PROBABILITY GRID	MUHL	
	DISTANT FACILITY SCHOENFELD	INITIALS
TITLE RSL DISTRIBUTION (SINGLE RECEIVER)	REFERENCE 81 km., 8 GHz.	





$D = 99.6$ km $\quad a = 4247$ km

$h_1 = 48.8$ m $\quad k = 0.667 \quad \frac{\Delta N}{\Delta h} = +78.5$ N-units/km $\quad h_2 = 30.5$ m

Feldberg-Schwarzenborn terrain profile.

DATA SHEET

B-1: LOS SYSTEM PARAMETERS

SITE NO. 1 (Tx)	DATE
FELDBERG	8 Apr 76
SITE NO. 2 (Rx)	**LINK NO.**
SCHWARZENBORN	MØ795

PATH PARAMETERS

TYPE CLIMATE	TYPE TERRAIN	PATH LENGTH	PATH CLEARANCE (Minimum) FRESNEL ZONES (@ K = 2/3)	FRESNEL ZONES (@ K = 4/3)
[XX] HUMID [ ] NORMAL [ ] DRY	[ ] SMOOTH [XX] NORMAL [ ] ROUGH	99.57 km	Clear	Clear

ANTENNA SYSTEM

PRIMARY ANTENNA

	TYPE	SIZE	GAIN	BEAMWIDTH
DISTANT Tx	Parabolic	3.048 m	45.5 dB	(.85°) rad
LOCAL Rx	Parabolic	3.048 m	45.5 dB	(.85°) rad

TRANSMISSION LINE

	TYPE	DESIGNATION	LENGTH	LOSS	VSWR
DISTANT Tx	Waveguide	EW-71 WC-166	16.2 m 42.7 m	1.06 dB 0.9 dB	1.06 MAX 1.04 MAX
LOCAL Rx	Waveguide	EW-71	40.5 m	2.66 dB	1.06 MAX

PASSIVE REFLECTOR (Periscope System)

	SIZE	SHAPE	DISTANCE/PRIMARY ANTENNA
DISTANT Tx	N/A m		m
LOCAL Rx	m		m

PASSIVE REFLECTOR (Mid-Path)

SIZE	m
DISTANCE FROM Tx	m
DISTANCE FROM Rx	m
INCLUDED HORIZONTAL ANGLE	deg

MISCELLANEOUS LOSSES (dB)

SOURCE	ACTUAL	ESTIMATED
Waveguide Loss		4.6
Waveguide Transitions and Connector Loss		2.4
Pressure Window, RADOME, Rectangular Section		1.2
TOTAL		8.2

EQUIPMENT SPECIFICATIONS

TRANSMITTER POWER	RECEIVER NOISE FIGURE	RECEIVER IF BANDWIDTH	RADIO CHNL CAPACITY	FM DEVIATION (Per Channel RMS)
37 dBm	12 dB	20.422 MHz	600 Channels	140 KHz

OPERATING FREQUENCIES TX 1	TX 2	RX 1	RX 2	RADIO NPR SPECIFICATION	FULLY QUIETED RECEIVER THERMAL NOISE
8 GHz	GHz	8 GHz	GHz	57 dB	10 pWCO

BASEBAND FREQUENCIES LOWER	HIGHER	PRE-EMPHASIS AVAL	TOP CHNL GAIN	MULTIPLEX NOISE SPECIFICATION LOADED	UNLOADED
60 KHz	2540 KHz	[XX] YES [ ] NO	dB	1/2 MUX 19 dBrnCO	1/2 MUX 18 dBrnCO

DIVERSITY CONFIGURATION

DIVERSITY ORDER	TYPE	SEPARATION (If applicable) FREQUENCY	ANTENNA	TYPE COMBINER
Dual	Space	N/A GHz	10 m	MAX/RATIO

DATA SHEET	SITE NO. 1 (Tx)	DATE
B-2: LOS PATH CALCULATIONS	FELDBERG	8 Apr 76
	SITE NO. 2 (Rx)	LINK NO.
	SCHWARZENBORN	MØ795

ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
1	Transmitter Power	** 37	dBm	Manufacturer's Specifications
2a	Primary Antenna Gain	** 91	dB	Manufacturer's Specifications
2b	Passive Reflector Gain	N/A	dB	See Attachment 2
2c	Total Antenna Gain	91	dB	Item 2a + Item 2b
3	Operating Frequency *(Mean)*	8	GHz	Link Specifications
4	Path Length	99.57	km	From Path Profile
5	Basic Transmission Loss	150.5	dB	20 log (Item 3) + 20 log (Item 4) + 92.5
6	Obstruction Loss @ K = 4/3	0	dB	See Figure 3-1
7	Obstruction Loss @ K = 2/3	0	dB	See Figure 3-1
8	Line and Miscellaneous Losses	8.2	dB	Manufacturer's Specifications
9a	Median Received Signal Level *(Single Receiver)*, K = 4/3	-30.7	dBm	Item 1 + Item 2c – Item 5 – Item 6 – Item 8
9b	Faded Median Received Signal Level *(Single Receiver)*, K = 2/3	-30.7	dBm	Item 1 + Item 2c – Item 5 – Item 7 – Item 8
10	Thermal Noise per Hz of Bandwidth	– 174	dBm	For T = 290 deg K
11	Receiver IF Bandwidth	** 20.422	MHz	Manufacturer's Specifications
12	IF Bandwidth in dB	73.1	dB	60 + 10 log (Item 11)
13	Receiver Noise Figure	** 12	dB	Manufacturer's Specifications
14	Receiver Noise Threshold	-88.9	dBm	Item 10 + Item 12 + Item 13
15	Median Carrier-to-Noise Ratio	58.2	dB	Item 9a – Item 14
16	Receiver FM Threshold	-78.9	dBm	10 + Item 14
17	Fade Margin	48.2	dB	Item 9a – Item 16 + Item 6 – Item 7
18	Climate Factor	1/2		Humid = 1/2 Normal = 1/4 Dry = 1/8
19	Terrain Factor	1		Smooth = 4 Normal = 1 Rough = 1/4
20	Single Receiver Outage Probability	* 0.00429	%	$5.1 \times 10^{-7} \times$ Item 18 $\times$ Item 19 $\times$ (Item 3)$^{1.5} \times$ (Item 4)^{3} $\times$ Antilog $\left[\frac{-\text{Item 17}}{10}\right]$ SEE NOTE 1
21a	Factor for Frequency Diversity Improvement	N/A		Freq = 4 GHz, 1/2 Freq = 8 GHz, 1/8 Freq = 12 GHz, 1/12

ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
21b	Frequency Separation	N/A	GHz	Link Specifications
21c	Frequency Diversity Improvement	N/A		Item 21a x $\frac{\text{(Item 21b)}}{\text{(Item 3)}}$ x antilog $\left[\frac{\text{Item 17}}{10}\right]$
22a	Antenna Separation	10	m	Link Specifications
22b	Space Diversity Improvement	* 640		1.2 x 10^{-3} x Item 3 x (Item 22a)^2 x antilog $\left[\frac{\text{Item 17}}{10}\right]$ / Item 4 SEE NOTE 1
23	Diversity Outage Probability	0.0000067		Item 20/Item 21c or Item 20/Item 22b
24	Radio Channel Capacity	** 600		Manufacturer's Specifications
25	Per Channel RMS Deviation	** 140	KHz	Link Specifications
26	Load Factor	** 17.78	dBmO	See text and Figure 3-2
27	Load Factor	7.74		Antilog $\left[\frac{\text{Item 26}}{20}\right]$
28	Peak Deviation	4832.5	KHz	Item 25 x Item 27 x 4.46
30	Highest Modulating Frequency	** 2540	KHz	See text and Figure 3-3
30	Modulation Index	1.9		Item 28/Item 29
31	Required IF Bandwidth	19.825	MHz	10^{-3} x (2 x Item 28 + 4 x Item 29) *(NOTE: Bandwidth of Item 11 must exceed this.)*
32	Diversity Improvement Factor	** 3	dB	Figure 3-4 for type combiner used
33	FM Improvement Factor	-25.17	dB	20 log (Item 25/Item 29)
34	Correction Factor for Voice Channel Bandwidth	38.2	dB	10 log (Item 11/3.1) + 30
35	Pre-emphasis Improvement	** 4	dB	Manufacturer's Specifications
36a	Channel Signal-to-Noise Ratio, Front-End Noise Only	78.3	dB	Item 15 + Item 32 + Item 33 + Item 34 + Item 35
36b	Channel Thermal Noise, Front-End Only	10.2	dBrnCO	88.5 – Item 36a
36c	Channel Thermal Noise, Front-End Only	10	pWCO	Antilog $\left[\frac{\text{Item 36b}}{10}\right]$
37	Noise Power Ratio	** 57	dB	Manufacturer's Specifications
38	Baseband Width	** 2480	KHz	Link Specifications or Figure 3-3
39a	Channel Signal-to-Noise Ratio, Idle and Intermodulation Noise Only	68.2	dB	Item 37 + 10 log (Item 38/3.1) – Item 26
39b	Channel Noise, Radio Equipment Only	20.3	dBrnCO	88.5 – Item 39a
39c	Channel Noise, Radio Equipment Only	107	pWCO	Antilog $\left[\frac{\text{Item 39b}}{10}\right]$
40	Fully Quieted Receiver Thermal Noise	10	pWCO	See Text
41a	Total Transmission Media Noise, Per Channel	117	pWCO	Item 36c + Item 39c

DATA SHEET	SITE NO. 1 (Tx)	DATE
B-2: LOS PATH CALCULATIONS *(CONTINUATION)*	FELDBERG	8 Apr 76
	SITE NO. 2 (Rx)	LINK NO.
	SCHWARZENBORN	MØ795

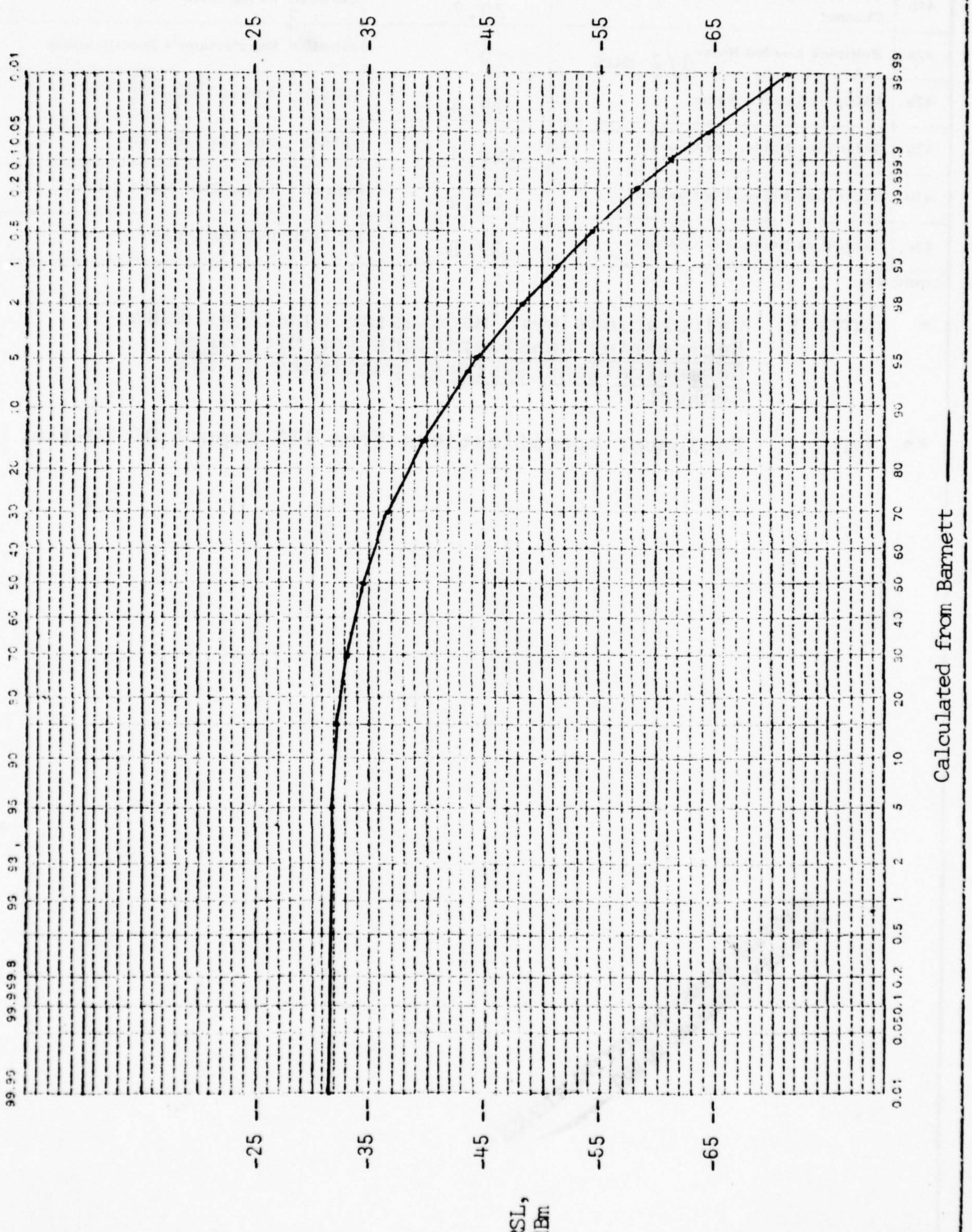
ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
41b	Total Transmission Media Noise, Per Channel	20.7	dBrnCO	10 log (Item 41a)
42a	Multiplex Loaded Noise 1/2 mux	19	dBrnCO	Manufacturer's Specifications
42b	Multiplex Loaded Noise	79.4	pWCO	Antilog $\left[\frac{\text{Item 42a}}{10}\right]$
43a	Total Link Noise, Per Channel	196.4	pWCO	Item 41a + Item 42b
43b	Total Link Noise, Per Channel	24.4	dBrnO	10 log (Item 43a) + 1.5
43c	Total Link Noise, Per Channel	22.9	dBrnCO	Item 43b − 1.5

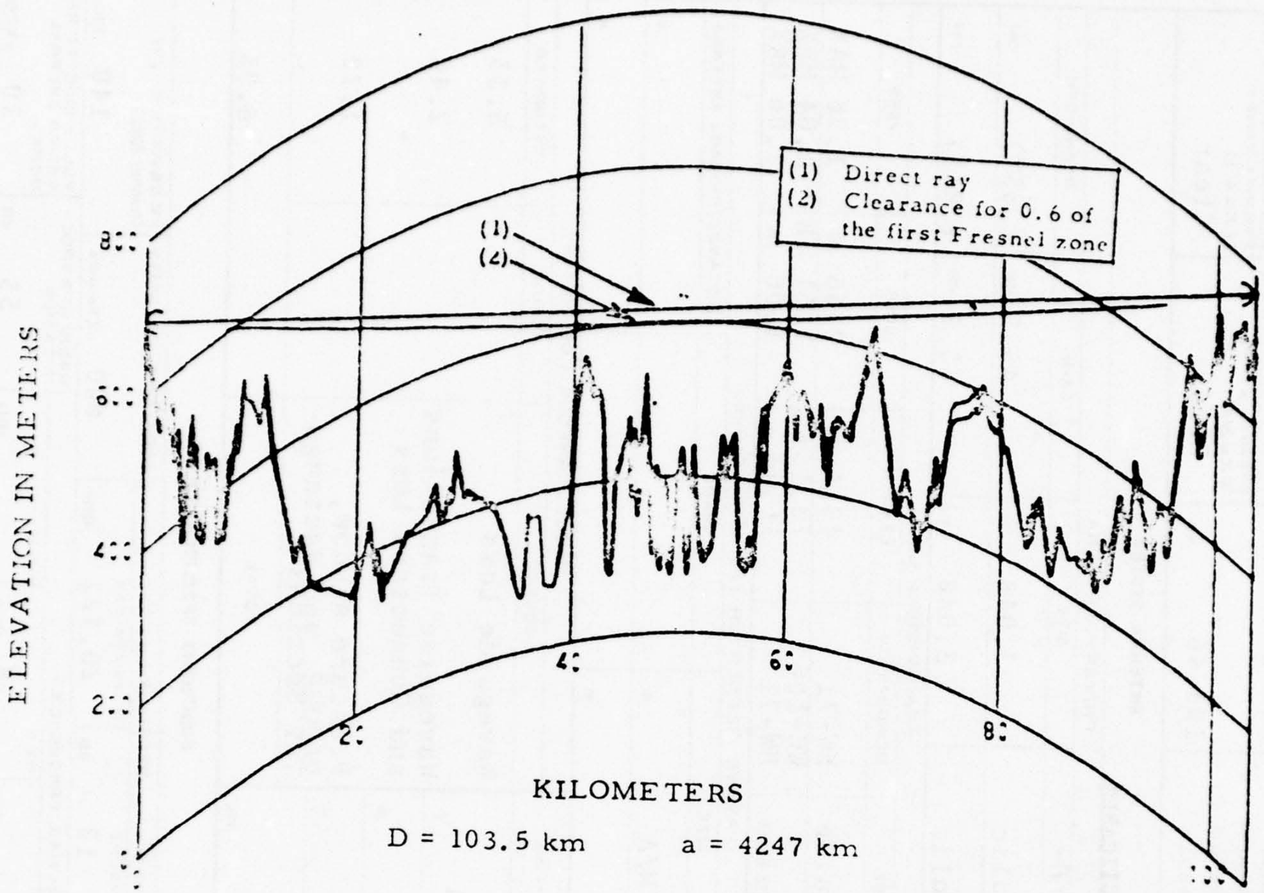
COMMENTS

* NOTE 1. Calculations were made using equations from Engineering Considerations for Microwave Communications Systems, published by GTE Lenkurt.

** NOTE 2. Equipment specifications from ITS Report OT TM-116.

DATA SHEET	FACILITY TESTED	DATE
A-6: PROBABILITY GRID	FELDBERG	
	DISTANT FACILITY	INITIALS
	SCHWARZENBORN	
TITLE	REFERENCE	
RSL DISTRIBUTION (SINGLE RECEIVER)	100 km., 8 GHz	





D = 103.5 km a = 4247 km

h_1 = 30.5 m k = 0.667 $\frac{\Delta N}{\Delta h}$ = + 78.5 N-units/km h_2 = 79.2 m

Adenau-Feldberg terrain profile.

DATA SHEET	SITE NO. 1 (Tx)	DATE
B-1: LOS SYSTEM PARAMETERS	ADENAU	8 Apr 76
	SITE NO. 2 (Rx)	LINK NO.
	FELDBERG	MØ891

PATH PARAMETERS

TYPE CLIMATE	TYPE TERRAIN	PATH LENGTH	PATH CLEARANCE (Minimum) FRESNEL ZONES (@ K = 2/3)	FRESNEL ZONES (@ K = 4/3)
[XX] HUMID / [ ] NORMAL / [ ] DRY	[ ] SMOOTH / [XX] NORMAL / [ ] ROUGH	103.46 km	Clear	Clear

ANTENNA SYSTEM

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PRIMARY ANTENNA

	TYPE	SIZE	GAIN	BEAMWIDTH
DISTANT TX	Parabolic	3.048 m	45.5 dB	(.85°) rad
LOCAL RX	Parabolic	3.048 m	45.5 dB	(.85°) rad

TRANSMISSION LINE

	TYPE	DESIGNATION	LENGTH	LOSS	VSWR
DISTANT TX	Waveguide	EW-71	40.5 m	2.66 dB	1.06 MAX
LOCAL RX		WC-166	73.15m	1.61 dB	1.04 MAX
	Waveguide	EW-71	16.15 m	1.06 dB	1.06 MAX

PASSIVE REFLECTOR (Periscope System)

	SIZE	SHAPE	DISTANCE/PRIMARY ANTENNA
DISTANT TX	N/A m		m
LOCAL RX	m		m

PASSIVE REFLECTOR (Mid-Path)		
SIZE		N/A m
DISTANCE FROM	Tx	m
	Rx	m
INCLUDED HORIZONTAL ANGLE		deg

MISCELLANEOUS LOSSES (dB)

SOURCE	ACTUAL	ESTIMATED
Waveguide Loss		5.33
Waveguide Transitions and Connectors Loss		2.40
Pressure Window, RADOME, and Rectangular Sections		1.20
TOTAL		8.93

EQUIPMENT SPECIFICATIONS

TRANSMITTER POWER	RECEIVER NOISE FIGURE	RECEIVER IF BANDWIDTH	RADIO CHNL CAPACITY	FM DEVIATION (Per Channel RMS)
37 dBm	12 dB	20.422 MHz	600 Channels	140 KHz

OPERATING FREQUENCIES TX 1	TX 2	RX 1	RX 2	RADIO NPR SPECIFICATION	FULLY QUIETED RECEIVER THERMAL NOISE
8 GHz	GHz	8 GHz	GHz	55 dB	10 pWCO

BASEBAND FREQUENCIES LOWER	HIGHER	PRE-EMPHASIS AVAL	TOP CHNL GAIN	MULTIPLEX NOISE SPECIFICATION LOADED	UNLOADED
60 KHz	2540 KHz	[XX] YES / [ ] NO	dB	22 dBrnCO	21 dBrnCO

DIVERSITY CONFIGURATION

DIVERSITY ORDER	DIVERSITY TYPE	SEPARATION (If applicable) FREQUENCY	ANTENNA	TYPE COMBINER
Dual	Space	N/A GHz	10 m	MAX/RATIO

AFCS FORM JUL 72 705 REPLACES AFCS FORMS 514 & 514A, MAY 69, WHICH ARE OBSOLETE.

DATA SHEET

B-2: LOS PATH CALCULATIONS

SITE NO. 1 (Tx)	DATE
ADENAU	8 Apr 76
SITE NO. 2 (Rx)	**LINK NO.**
FELDBERG	MØ891

ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
1	Transmitter Power	37	dBm	Manufacturer's Specifications
2a	Primary Antenna Gain	91	dB	Manufacturer's Specifications
2b	Passive Reflector Gain	N/A	dB	See Attachment 2
2c	Total Antenna Gain	91	dB	Item 2a + Item 2b
3	Operating Frequency *(Mean)*	8	GHz	Link Specifications
4	Path Length	103.5	km	From Path Profile
5	Basic Transmission Loss	150.8	dB	20 log (Item 3) + 20 log (Item 4) + 92.5
6	Obstruction Loss @ K = 4/3	0	dB	See Figure 3-1
7	Obstruction Loss @ K = 2/3	0	dB	See Figure 3-1
8	Line and Miscellaneous Losses	8.93	dB	Manufacturer's Specifications
9a	Median Received Signal Level *(Single Receiver)*, K = 4/3	-31.7	dBm	Item 1 + Item 2c – Item 5 – Item 6 – Item 8
9b	Faded Median Received Signal Level *(Single Receiver)*, K = 2/3	-31.7	dBm	Item 1 + Item 2c – Item 5 – Item 7 – Item 8
10	Thermal Noise per Hz of Bandwidth	– 174	dBm	For T = 290 deg K
11	Receiver IF Bandwidth	20.422	MHz	Manufacturer's Specifications
12	IF Bandwidth in dB	73.1	dB	60 + 10 log (Item 11)
13	Receiver Noise Figure	12	dB	Manufacturer's Specifications
14	Receiver Noise Threshold	-88.9	dBm	Item 10 + Item 12 + Item 13
15	Median Carrier-to-Noise Ratio	57.2	dB	Item 9a – Item 14
16	Receiver FM Threshold	-78.9	dBm	10 + Item 14
17	Fade Margin	47.2	dB	Item 9a – Item 16 + Item 6 – Item 7
18	Climate Factor	1/2		Humid = 1/2 Normal = 1/4 Dry = 1/8
19	Terrain Factor	1		Smooth = 4 Normal = 1 Rough = 1/4
20	Single Receiver Outage Probability	* 0.00589	%	$5.1 \times 10^{-7} \times$ Item 18 $\times$ Item 19 $\times$ (Item 3)$^{1.5}$ $\times$ (Item 4)^{3} $\times$ Antilog $\left[\frac{-\text{Item } 17}{10}\right]$ SEE NOTE 1
21a	Factor for Frequency Diversity Improvement	N/A		Freq = 4 GHz, 1/2 Freq = 8 GHz, 1/8 Freq = 12 GHz, 1/12

ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
21b	Frequency Separation	N/A	GHz	Link Specifications
21c	Frequency Diversity Improvement	N/A		Item 21a x $\frac{\text{(Item 21b)}}{\text{(Item 3)}}$ x antilog $\left[\frac{\text{Item 17}}{10}\right]$
22a	Antenna Separation	10	m	Link Specifications
22b	Space Diversity Improvement	* 491		1.2×10^{-3} x Item 3 x (Item 22a)^2 x antilog $\left[\frac{\text{Item 17}}{10}\right]$/ Item 4 SEE NOTE 1
23	Diversity Outage Probability	0.000012		Item 20/Item 21c or Item 20/Item 22b
24	Radio Channel Capacity	** 600		Manufacturer's Specifications
25	Per Channel RMS Deviation	** 140	KHz	Link Specifications
26	Load Factor	17.78	dBmO	See text and Figure 3-2
27	Load Factor	7.74		Antilog $\left[\frac{\text{Item 26}}{20}\right]$
29	Peak Deviation	4832	KHz	Item 25 x Item 27 x 4.46
30	Highest Modulating Frequency	** 2540	KHz	See text and Figure 3-3
30	Modulation Index	1.9		Item 28/Item 29
31	Required IF Bandwidth	19.825	MHz	10^{-3} x (2 x Item 28 + 4 x Item 29) *(NOTE: Bandwidth of Item 11 must exceed this.)*
32	Diversity Improvement Factor	* 3	dB	Figure 3-4 for type combiner used
33	FM Improvement Factor	-25.1	dB	20 log (Item 25/Item 29)
34	Correction Factor for Voice Channel Bandwidth	38.2	dB	10 log (Item 11/3.1) + 30
35	Pre-emphasis Improvement	* 4	dB	Manufacturer's Specifications
36a	Channel Signal-to-Noise Ratio, Front-End Noise Only	77.3	dB	Item 15 + Item 32 + Item 33 + Item 34 + Item 35
36b	Channel Thermal Noise, Front-End Only	11.2	dBrnCO	88.5 – Item 36a
36c	Channel Thermal Noise, Front-End Only	13.2	pWCO	Antilog $\left[\frac{\text{Item 36b}}{10}\right]$
37	Noise Power Ratio	** 55	dB	Manufacturer's Specifications
38	Baseband Width	** 2480	KHz	Link Specifications or Figure 3-3
39a	Channel Signal-to-Noise Ratio, Idle and Intermodulation Noise Only	66.25	dB	Item 37 + 10 log (Item 38/3.1) – Item 26
39b	Channel Noise, Radio Equipment Only	22.25	dBrnCO	88.5 – Item 39a
39c	Channel Noise, Radio Equipment Only	167.8	pWCO	Antilog $\left[\frac{\text{Item 39b}}{10}\right]$
40	Fully Quieted Receiver Thermal Noise	10	pWCO	See Text
41a	Total Transmission Media Noise, Per Channel	181	pWCO	Item 36c + Item 39c

DATA SHEET **B-2: LOS PATH CALCULATIONS** *(CONTINUATION)*	SITE NO. 1 *(Tx)* ADENAU SITE NO. 2 *(Rx)* FELDBERG	DATE 8 Apr 76 LINK NO. MØ891

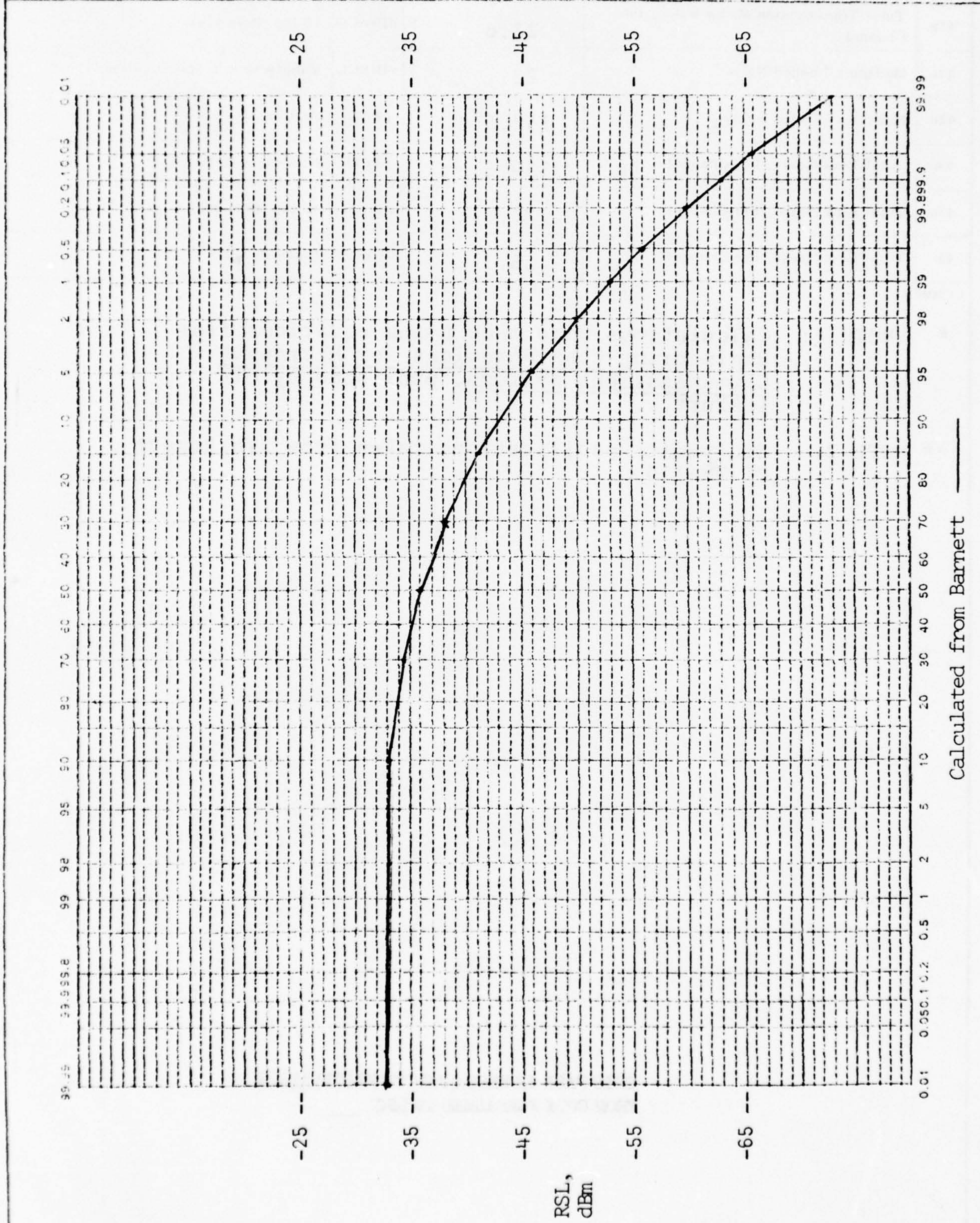
ITEM NO.	PERFORMANCE FACTOR	VALUE	UNITS	REMARKS
41b	Total Transmission Media Noise, Per Channel	22.6	dBrnCO	10 log (Item 41a)
42a	Multiplex Loaded Noise	22	dBrnCO	Manufacturer's Specifications
42b	Multiplex Loaded Noise	158.5	pWCO	Antilog $\left[\frac{\text{Item 42a}}{10}\right]$
43a	Total Link Noise, Per Channel	339.5	pWCO	Item 41a + Item 42b
43b	Total Link Noise, Per Channel	26.8	dBrnO	10 log (Item 43a) + 1.5
43c	Total Link Noise, Per Channel	25.3	dBrnCO	Item 43b − 1.5

COMMENTS

* NOTE 1: Calculations were made using equations from Engineering Considerations for Microwave Communications Systems, published by GTE Lenkurt.

** NOTE 2. Equipment specifications taken from ITS Report OT TM-116.

DATA SHEET	FACILITY TESTED	DATE
A-6: PROBABILITY GRID	FELDBERG	
	DISTANT FACILITY	INITIALS
	ADENAU	
TITLE	REFERENCE	
RSL DISTRIBUTION (SINGLE RECEIVER)	103 km., 8 GHz.	



APPENDIX B

PROPOSED STUDY

PROPOSED STUDY OF WEATHER EFFECTS ON THE DCS

I. The Problem

In October 1975, a series of catastrophic communication outages was experienced in West Germany on links of the Scope Comm System, among others. Communications were disrupted over a region of 500 km or more in diameter. The interruptions of service ranged from about an hour to nearly two days on individual links, although the system was afflicted to some degree for four days. Simultaneous outages on three or more links, as well as the apparent randomness of the outages hindered altrouting attempts.

This phenomena apparently recurred with less severity in late December 1975, and may have afflicted one link in February 1976. The inability of present theory to foresee these outages, combined with their potential occurence at inauspicious moments, would seem to justify study of the phenomena.

Engineers at AFCS were quite surprised by these outages, in light of the extraordinary design measures taken to achieve 99.999% ("five nines") path availability on each link. This five nines figure is the calculated performance necessary to achieve the noise standards of the DCS reference circuit, as outlined in DCA Circular 330-175-1 and MIL-STD-188-300. Consequently, the five nines figure was used as an engineering standard for Scope Comm, and subsequently Digital European Backbone

(DEB). The outages experienced since October 1975 represent not only the usage of ten to eight hundred years of predicted outage time, but also a failure to meet DCA standards.

II. Analysis

There is little doubt that the problems are attributable to weather induced propagation anomalies in the lowermost few hundred meters of the atmosphere. The high probability of some abnormal propagation conditions in the affected region was first confirmed by the 2nd Weather Wing and later substantiated by the AFCS Staff Weather Office. While the weather data available implied the presence of abnormal conditions, there are problems inherent in extrapolating observations taken at a weather station (with the intent of studying conditions aloft) to a radio site up to 100 km away, at a different elevation, and solely affected by the lowest few hundred meters of atmosphere. Currently available weather data lacks resolution - it is too "coarse" to define the meteorological conditions along an actual microwave path.

A similar problem exists with Performance Monitoring Program (PMP) data taken of radio Operational parameters. Once-a-day measurements of received signal level (RSL) and idle channel noise (ICN) are fine for monitoring long term (monthly to yearly) degradations; but cannot show conditions preceding, during and subsequent to an outage of only an hour or two.

Even though both anatomy and severity of the outages remains indeterminate, some potential solutions have been advanced. These proposals have ranged from equipment adjustment to the addition of repeater sites. However, it is clear that more must be known about these outages if any proposed solution is to have a reasonable assurance of success. Additional data is required to better understand the causes and to more intelligently present solutions or remedies to the situation. The general form of the required information is a set of atmospheric parameters recorded in the first few hundred meters above a site, and the corresponding received radio signal parameters. From this data, not only can statistics of the received signal be determined but also the correlation between the radio signal and local weather conditions. The detailed objectives of such a study are described below.

III. Objectives

The following study objectives are listed according to anticipated complexity and degree of generality - from simplest to most difficult and from most specific to most general. The desired objectives are worded as questions to be answered in the course of an investigation, and secondary questions which serve to clarify what is requested.

A. What conditions prevail near the affected sites prior to, during, and after the outages?

1. Are the atmospheric conditions subrefractive or superrefractive?

2. What are the characteristics of the received signal levels (RSL) in the pre-and post-outage periods? How low does RSL go during outages?

3. What is the atmospheric fine structure above the sites during outages?

The intent of this objective is to ascertain the nature and severity of the outages. This may be all the information required to establish a usable fix action or to identify impending problems in the formative, pre-outage stages. The accomplishment of this objective would involve the recording of radio and weather parameters during several outages or near outages, as well as during comparatively "normal" times to establish a reference. Some PMP or Air Weather Service (AWS) data may be deemed useful at this stage, so arrangements should be made to supply this data if requested. This objective is believed to provide the bare minimum of useful information not already known. The report prepared to satisfy this objective should answer the stated questions with tables, graphs, and atmospheric refractivity profiles as well as any significant observations of the investigators.

B. Does a microwave path exist from the vicinity of the transmitter to the vicinity of the receiver during these outages?

1. What range of RSL's (or path losses) are associated with the paths?

2. What is the range of incidence angles associated with the paths?

3. How does the RSL vary with antenna height (during outages)?

4. What techniques can be implemented to utilize these paths during outages?

The crux of this objective is to identify and characterize radio paths which can sustain communications when the presently used paths suffer outages. It is suspected that a path may exist at tree-top height with unusually elevated incidence angles, but other possibilities should be equally investigated. While it may be possible to complete part of this objective by simulation using meteorological data collected for objective A, it is hoped that the feasibility of paths so identified can be demonstrated during actual outage conditions. The product generated in this phase of the study should include a description of the methods used to locate potential paths, the results of these attempts and the efforts at verification. The values of radio parameters calculated or measured on the paths can be presented by summary statistics: sample means, variances, medians and ranges. A discussion and justification of methods proposed to utilize these paths should be included.

C. What are the descriptive statistics of received signal parameters on the affected links over a long period?

1. What are the statistics of RSL?

2. What are the statistics of the incidence (arrival) angles?

3. What are the joint statistics of RSL and incidence angles?

This objective becomes superfluous if objective B fails to identify any usable paths during outages. If usable paths <u>can</u> be found, then these statistics (gathered for both the normal and new paths) will indicate the value of these new paths as either replacement or supplemental diversity paths. The questions of arrival angle and its correlation to RSL seem to have been ignored in prior investigations, but may cause "decoupling blackout" of the high gain, narrow beamwidth Scope Comm antennas. The results of this portion of the study should be presented as summary statistics as well as a graphical presentation of probability distributions of RSL and incidence angle. Some effort should be made to express the probability distributions as analytical expressions.

D. What is the correlation of measured atmospheric conditions to signal parameters?

1. How are signal characteristics correlated to on-site weather measurements?

2. How are signal characteristics correlated with the usual (radiosonde and surface) weather observations taken in the region?

The thrust of this objective is twofold. In the first place, it is hoped that unusual atmospheric refraction conditions (as determined from on-site meteorological measurements) can be either confirmed or dismissed as causes of the outages. Secondly, a means of predicting outages is sought. The prediction would ideally be valid some six to twelve hours in advance and would be generated from weather data taken routinely at some point in the region of the radio site. A somewhat less attractive alternative would be prediction based on data especially collected at the affected sites, or on outages already experienced at some nearby site. The method of presenting results can be left fairly open, depending on what atmospheric parameters--singly or in combination--are found to be useful predictors of RSL, arrival angles, and/or outages. It is hoped that the timeliness and accuracy of any predictive model can be demonstrated using incidents which didn't contribute to developing the model. A discussion of the model's development, including samples of those cross-correlations which the researchers found interesting, should be included.

E. To what degree can the above results be generalized?

1. How can links susceptible to outages be identified?

2. How can susceptible links be improved?

3. Can the conclusions of these studies be applied to other areas of the world?

The most important portion of this objective is the ability to identify and alleviate--in the design stages--troublesome links. The development of this capability on a worldwide basis would expand the engineering capability of AFCS and increase the general reliability of future systems (including the latter stages of DEB). The goal of expanding the prediction techniques (if any) from objective D to global applicability has the potential for generating measurements and studies ad infinitum; that is not what is requested here. Instead, this should be the best engineering judgment of the people involved, based on the collected data as well as any other studies or reports available. The report should include, if possible, the criteria by which susceptible links may be identified and a discussion of possible fixes.

IV. Discussion

A few topics merit thought before a contract or tasking is finalized. The probability of success depends to a great degree on the presence of outages to study. While several links in central West Germany have been identified as being susceptible to outages, these outages occur in a seemingly unpredictable and random fashion. There can be no assurance that instruments located at any given site at any specific time will gather a useful body of data. Consequently, it is recommended that two or more susceptible sites be instrumented for a period of several months (suggest October through December) to a year or more, with the longer time spans being essential for objective C and D.

The question of government support--its nature and degree--also arises. The availability of whatever historical data (both radio and meteorological) which may exist has already been mentioned. The role of site personnel in acquiring data needs clarification. (What about unmanned locations?) AWS may be asked to supply not only measured weather data but perhaps weather measuring instruments, instrument maintenance or technical advice. Permission will certainly be sought to attach instruments or recording devices to towers and radios. Permission to test a possible fix may be sought. Other problem areas of a similar nature are certain to appear; some can probably be reduced to internal administrative matters by assigning the study to a government agency while others may be compounded by such a move.

It is obvious that a full fledged study, intended to achieve all the objectives outlined above would be a costly, multi-year effort. Therefore it is recommended that this task be approached in two steps: The first, short-term phase to address study objectives A and B, and the second, long-term phase to tackle objectives C, D and E.

The rationale underlying this recommendation is multifold. The present budget squeeze would seem to increase the probability of funding the shorter, lower cost project as opposed to the more expensive, long duration undertaking. A weightier consideration is that completion of objectives A and B would seem to provide a natural point of evaluation and re-orientation. The results of this first phase may dictate the use of a particular approach, or may cause some alteration of objectives C, D or E. Indeed, the results

obtained from the first phase may indicate that the second phase objectives are unlikely to be attained. Finally, it is believed that the long-term (phase two) effort will not uncover any potential solutions applicable to the immediate (central European) problem. The value of phase two lies, instead, in quantitatively assessing and optimizing the various solutions identified in phase one, and the extrapolation of these solutions to links not under study. If Phase Two is not undertaken, the evaluation of phase one solutions would occur in real-world operational applications.

V. Conclusion

A study designed to improve the reliability of the DCS by investigating the presently unknown long term propagation characteristics and their relationships to weather characteristics has been outlined. The study will run from three months to a year or more at a cost dependent on who is tasked to perform it and the results desired.

APPENDIX C

CROSSCORRELATIONS OF RECEIVED SIGNAL LEVEL (RSL)

Appendix C

Crosscorrelations of Received Signal Level (RSL)

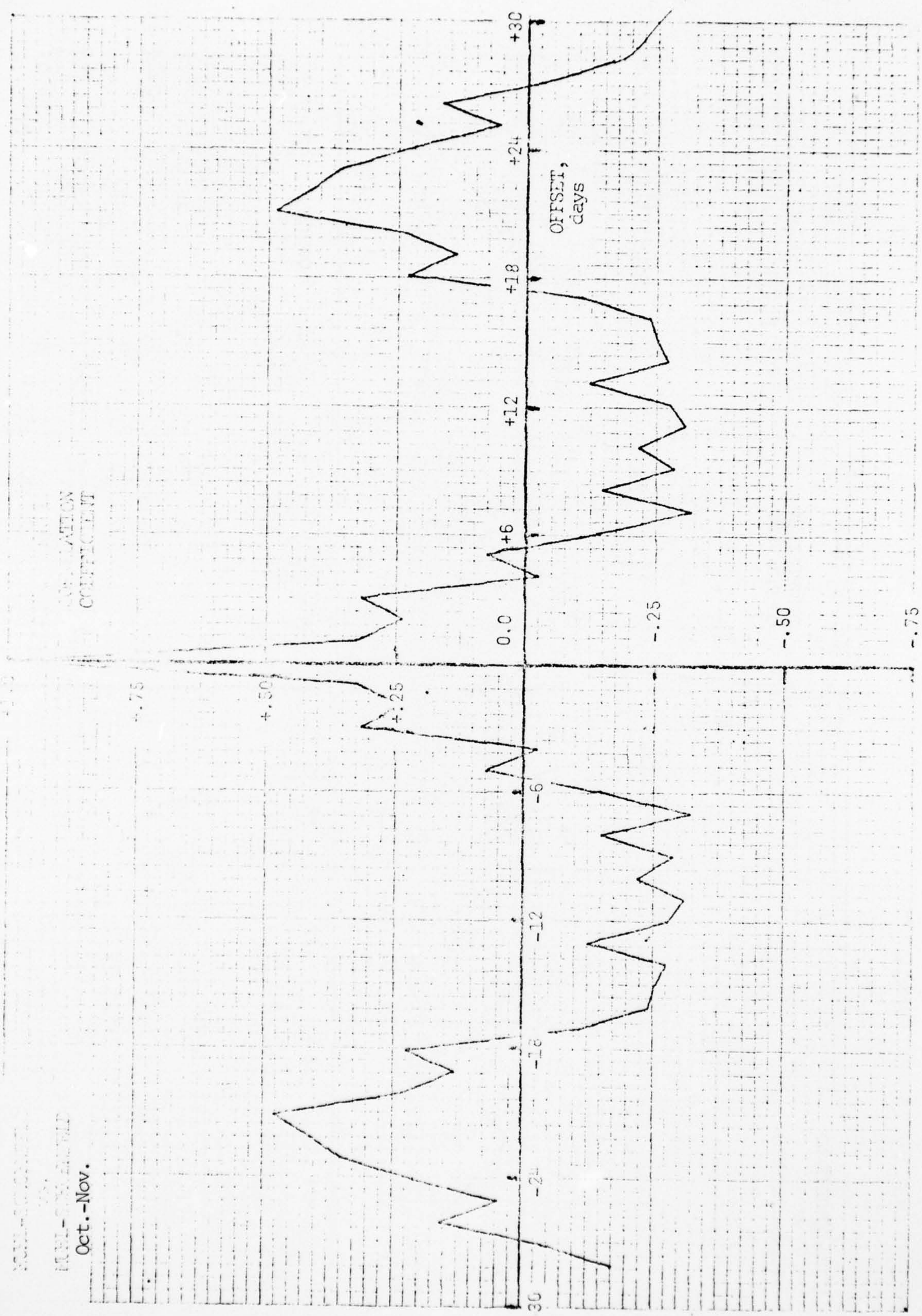
The correlation coefficient is a statistical measure of the dependance of one variable on another. Put another way, the correlation coefficient is indicative of the ability to predict the value of one variable based on knowledge of some other quantity. Positive correlations indicate direct proportionality while negative values imply inverse proportionality. A zero correlation indicates that the value of one of the variables gives no clue to the value of the other variable. The greater the (absolute) value of the correlation coefficient, the greater the accuracy of predicting one variable from another, while a zero correlation indicates that knowledge of one of the variables is of no value in predicting the other variable.

A few examples may be helpful. Consider correlating the RSL received at one end of a certain microwave link with itself. Intuition tells us that if RSL was just measured and is known, "predicting" its value is as easy as writing down this known value. The correlation coefficient for this case (+1.0) confirms this fact: its positive value shows that the RSL is directly proportional to itself, while its absolute value of 1.0 implies perfect correlation.

A more pertinent question is whether the current days value of RSL is correlated with readings taken several days ago or with RSL's of days yet to come. This is the

information presented in the attached graphs: correlaion coefficient versus days of offset. When such a function is generated by correlation one variable against itself, it is known as an "autocorrelation in time"; when two different variables are used, it's called "crosscorrelation in time".

The crosscorrelation of the following figures are computed using the period Oct 1975 thru Jan 1976 except where noted otherwise.


Oct.-Nov.
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OFFSET,
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+.50
+.25
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-.25
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+12
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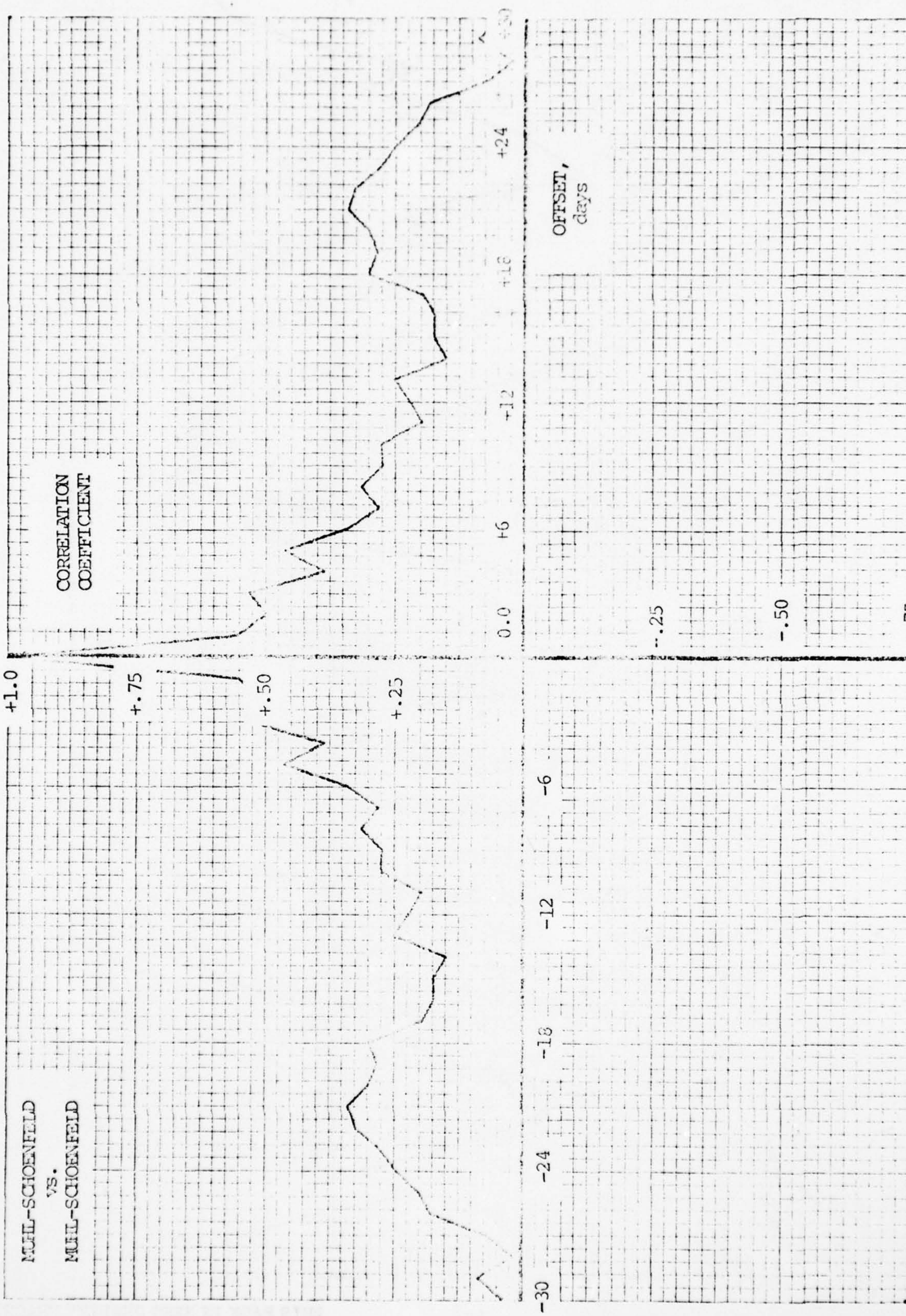
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vs.
MUHL-SCHOENFELD
CORRELATION
COEFFICIENT
OFFSET,
days
+1.0
+.75
+.50
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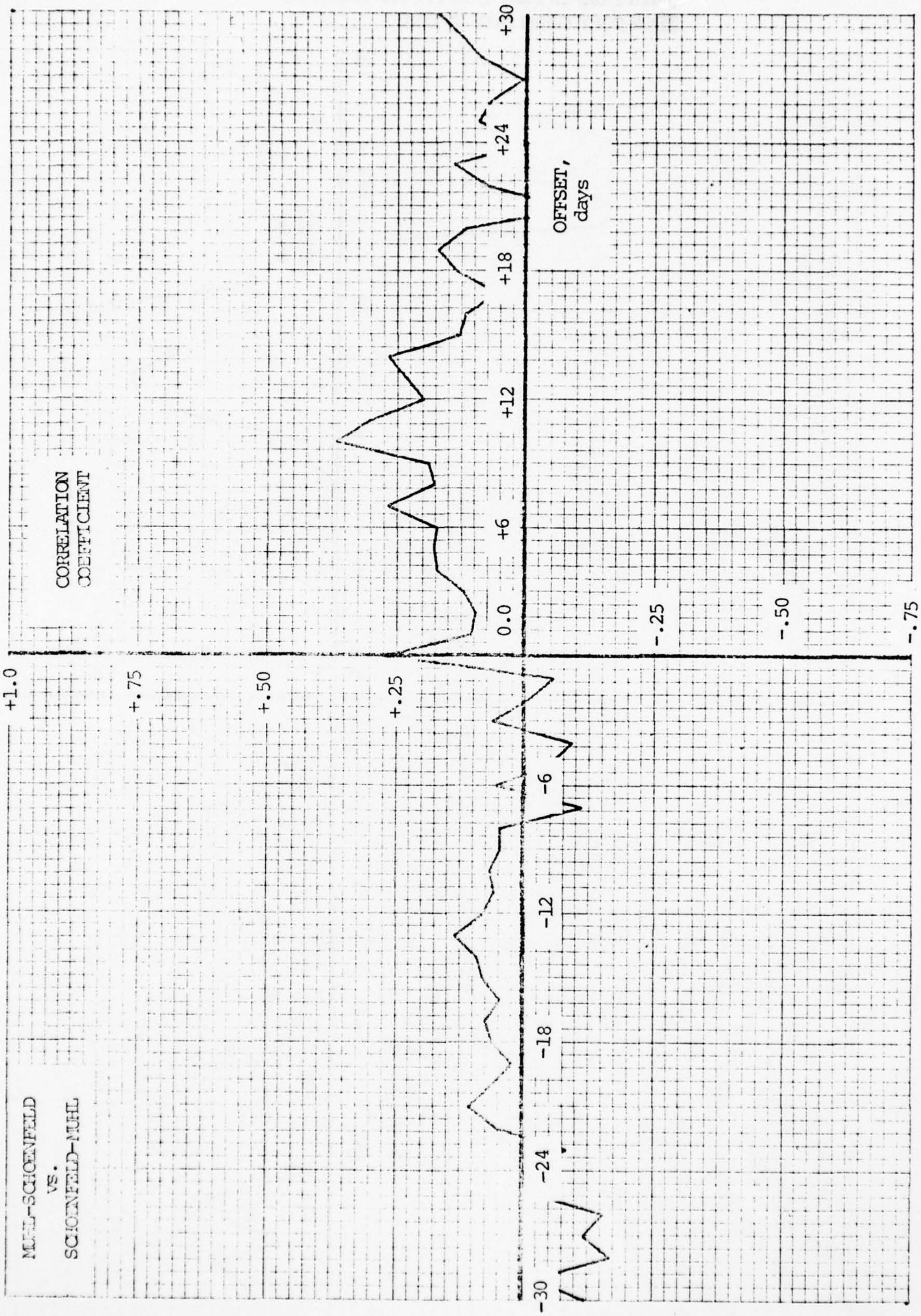
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SCHOENFELD-MUHL
CORRELATION
COEFFICIENT
OFFSET,
days
+1.0
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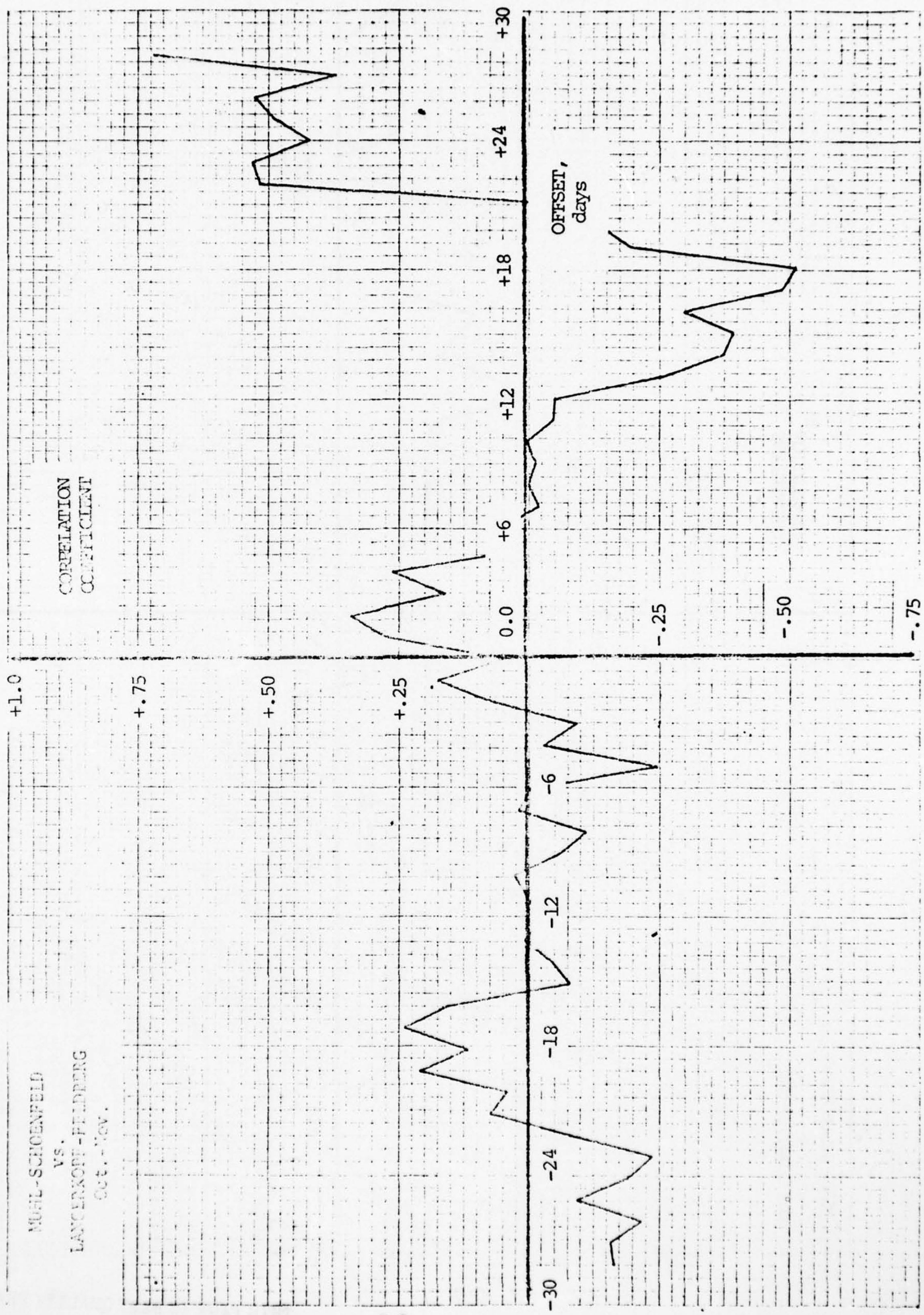

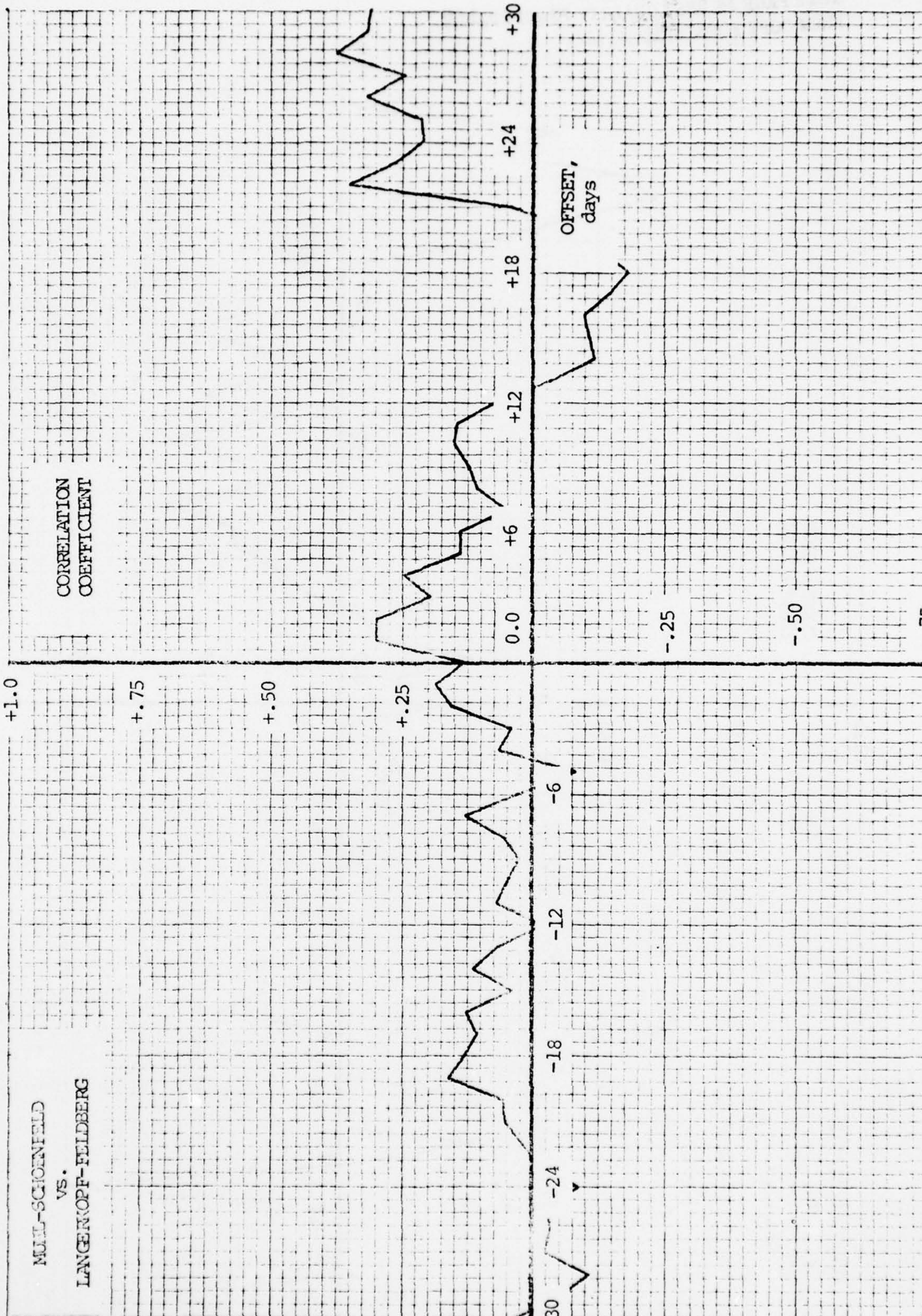

MUHL-SCHOENFELD
vs.
LANGENKOPF-FELDBERG
CORRELATION
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OFFSET,
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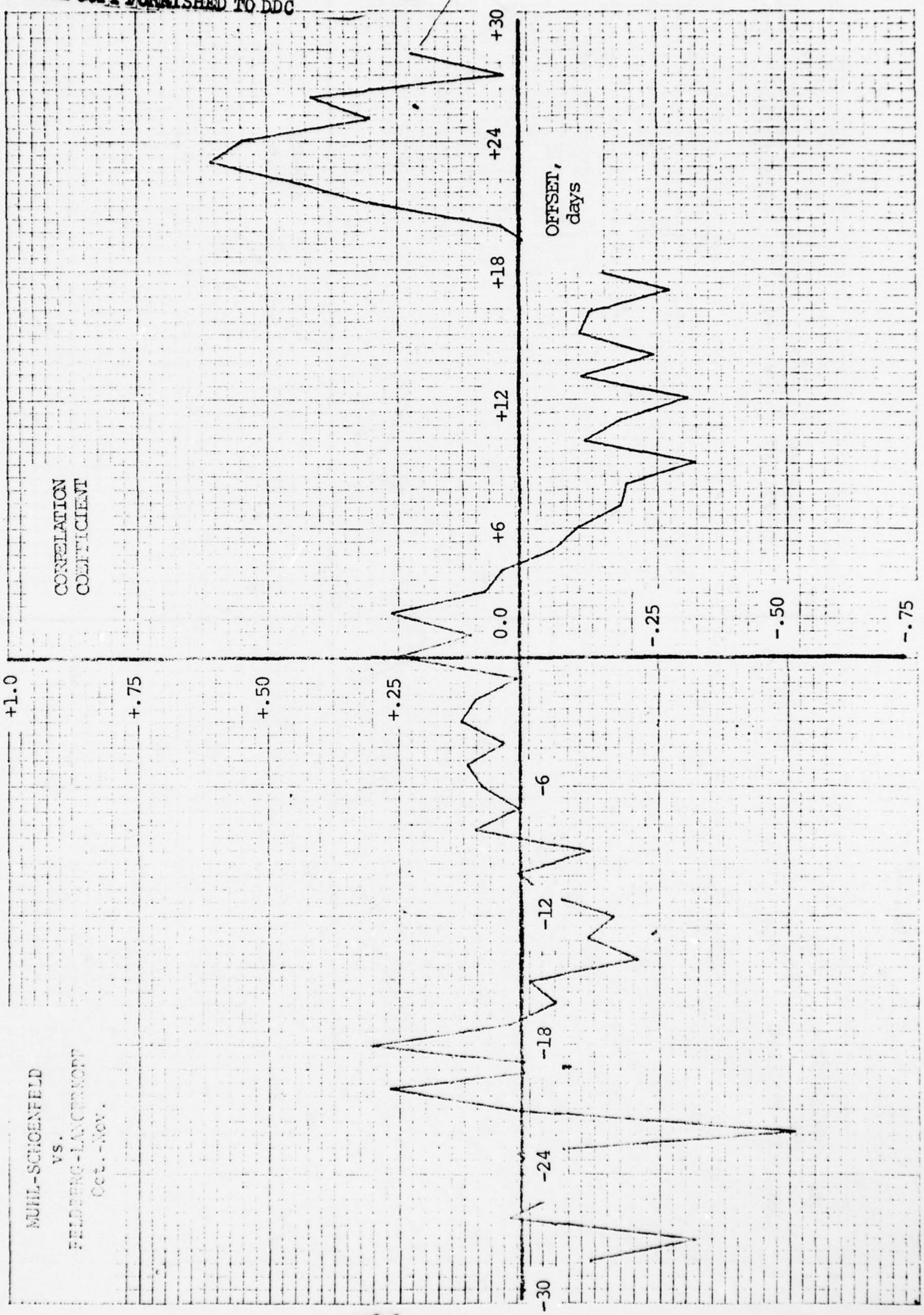
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vs.
Oct.-Nov.
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COEFFICIENT
OFFSET,
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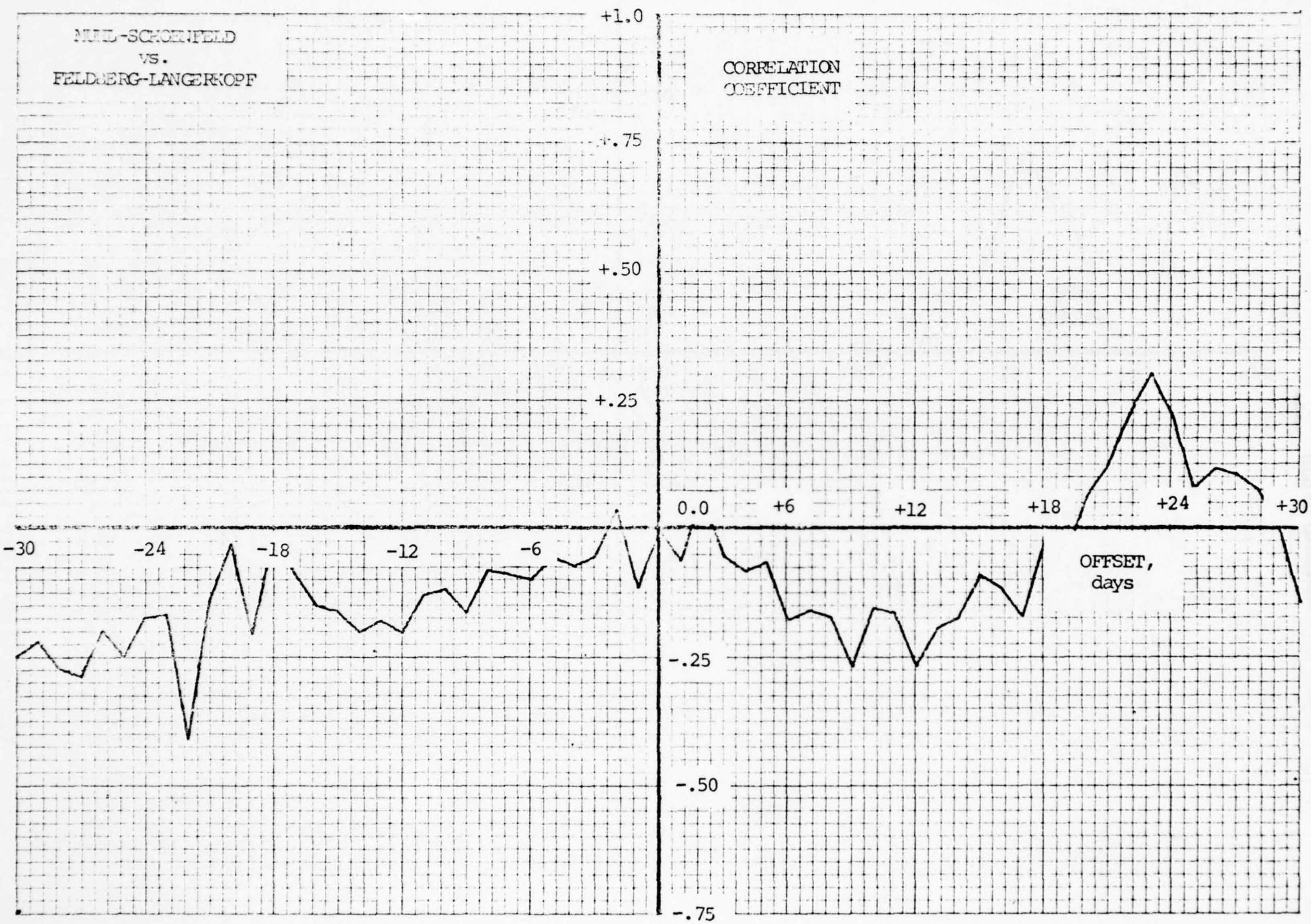
vs.
CORRELATION COEFFICIENT
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OFFSET, days

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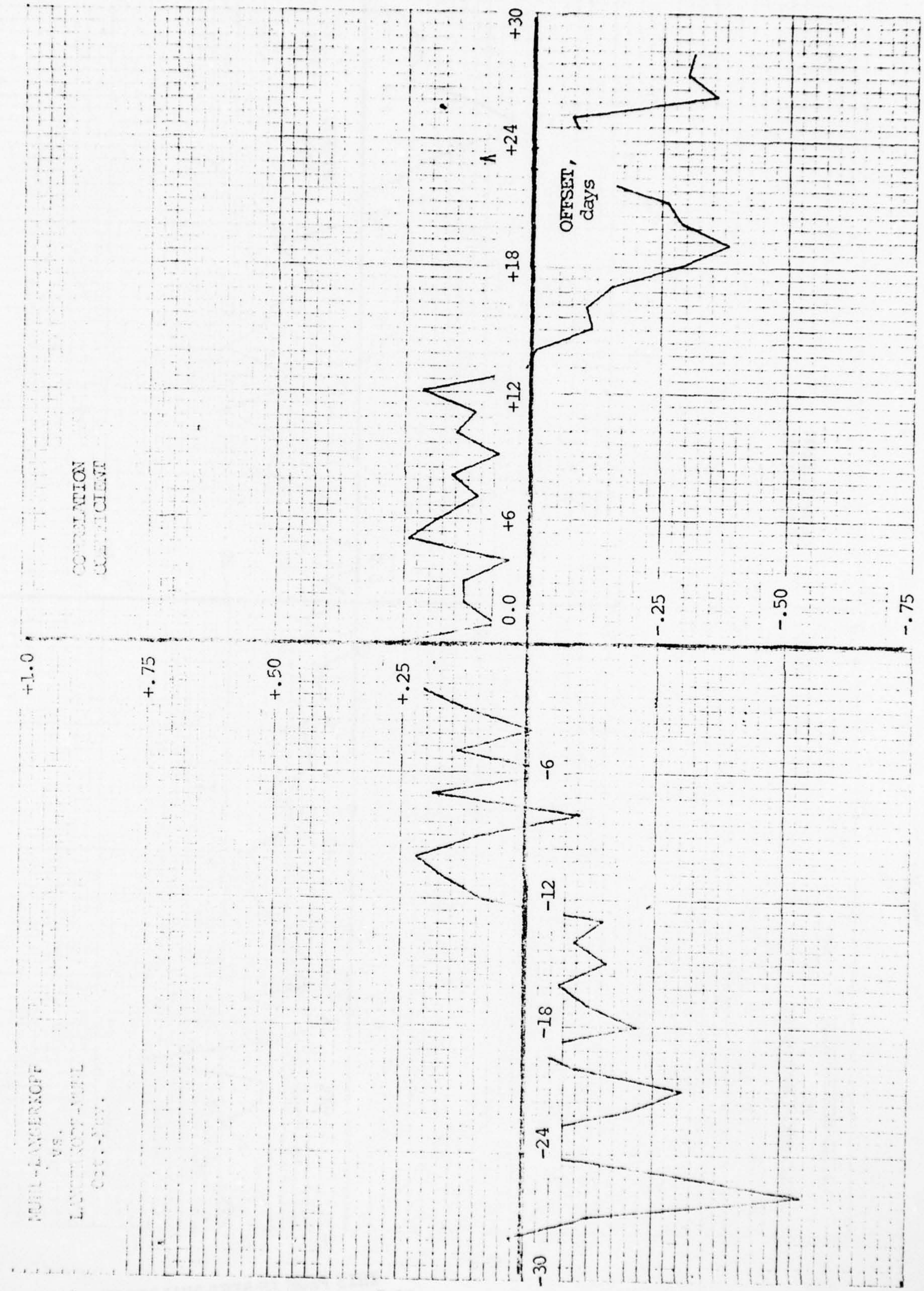

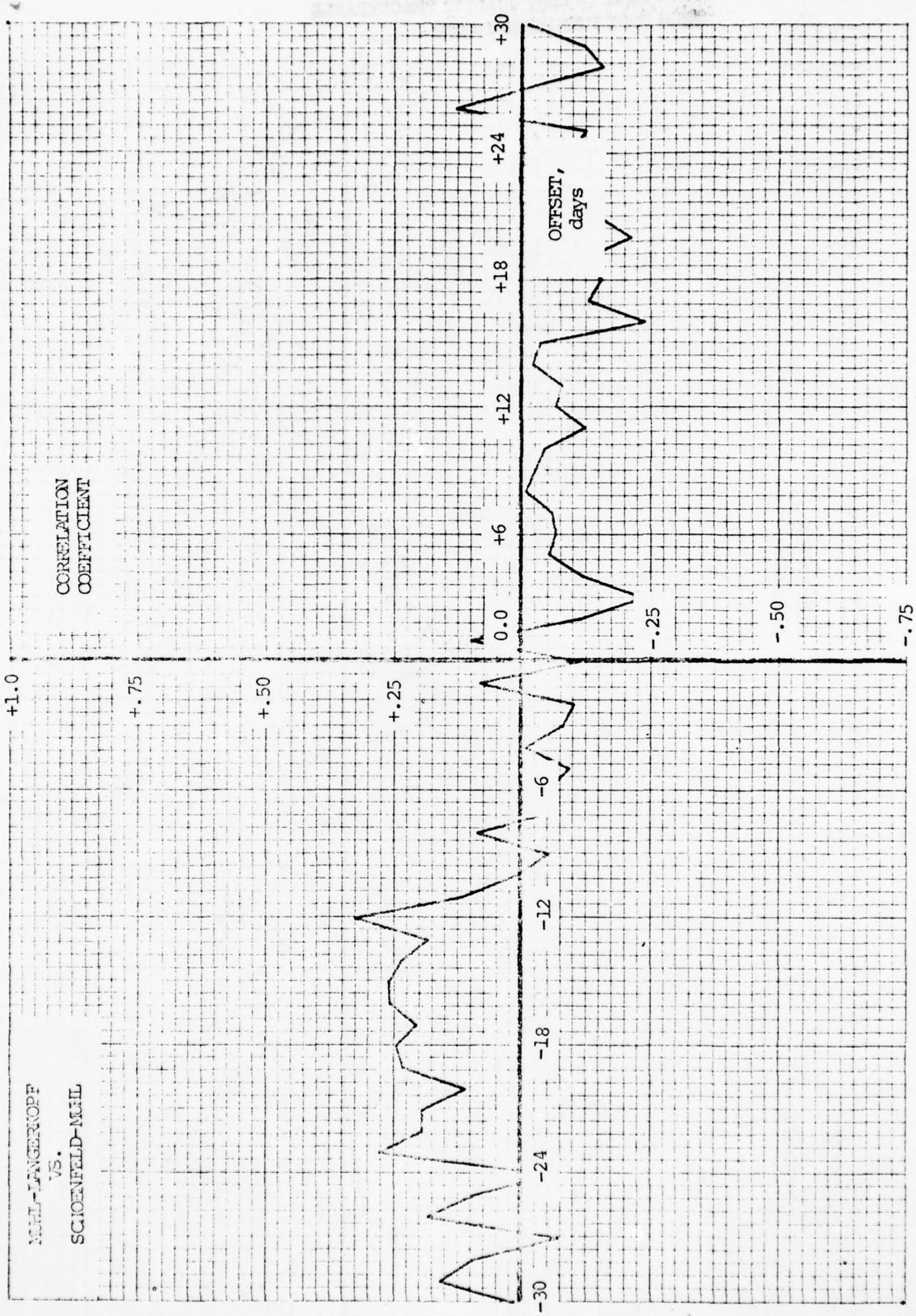
MUHL-LANGERKOPF
VS.
SCHOENFELD-MUHL
CORRELATION
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OFFSET,
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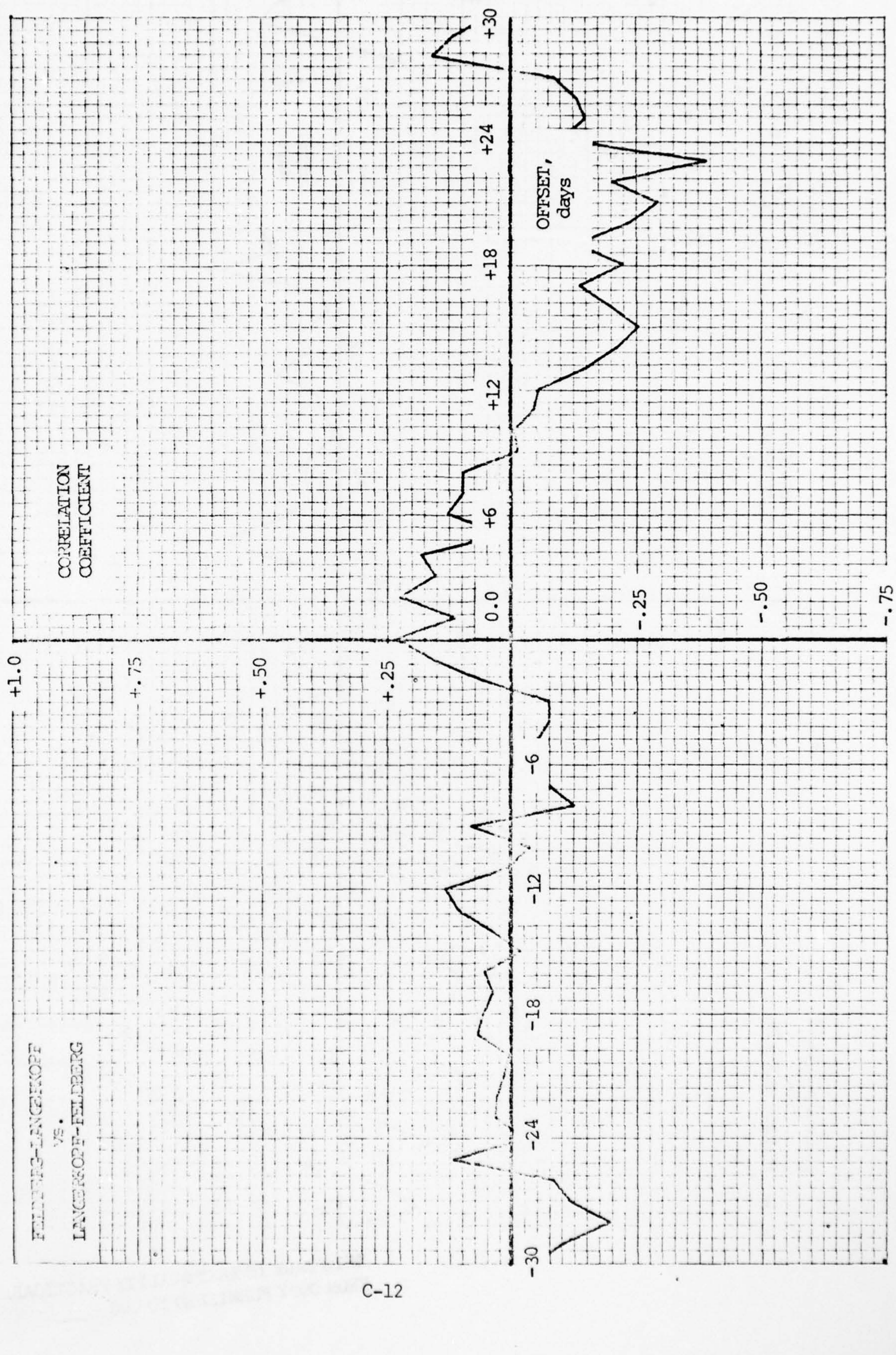

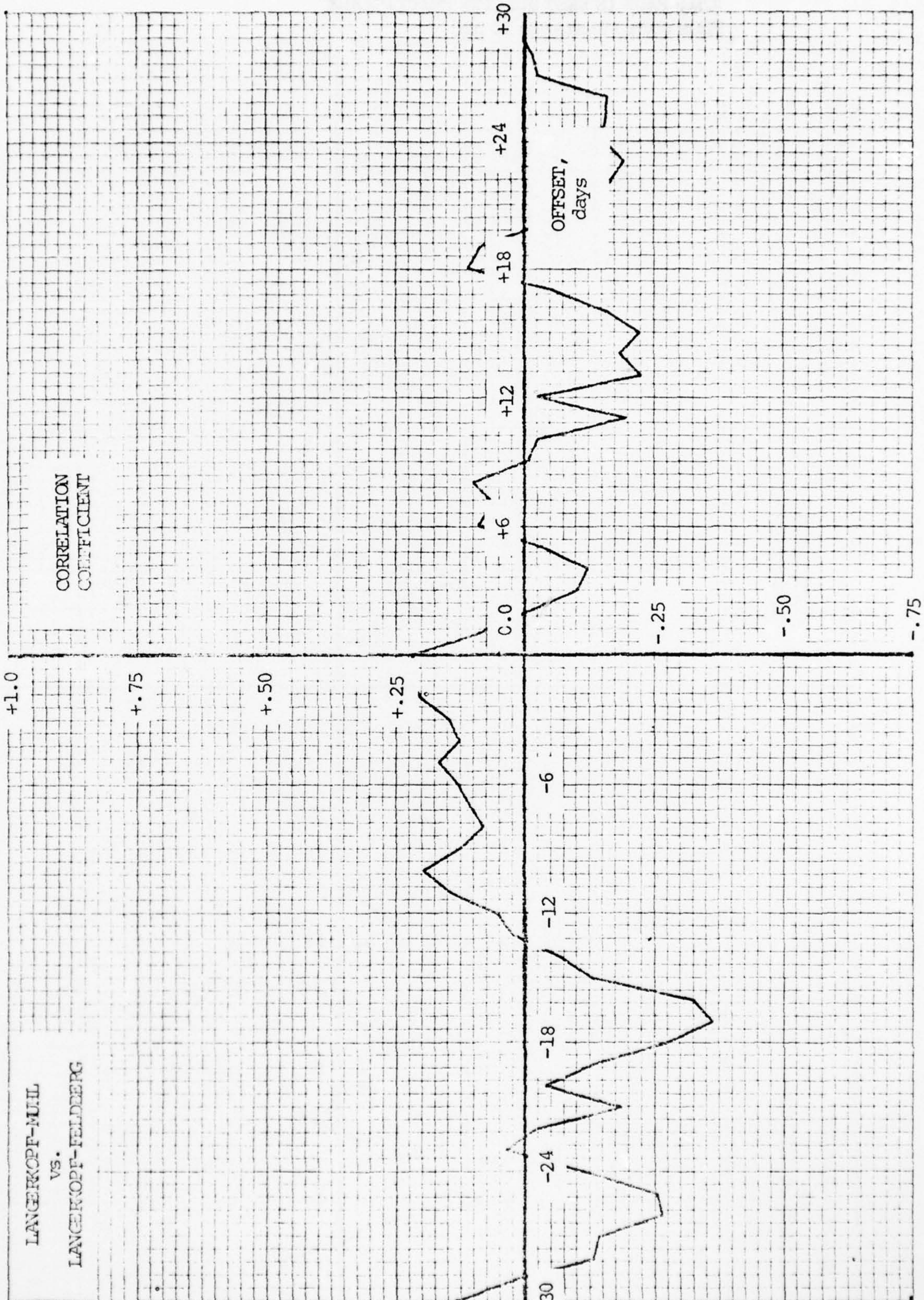
LANGERKOPF-MUIL
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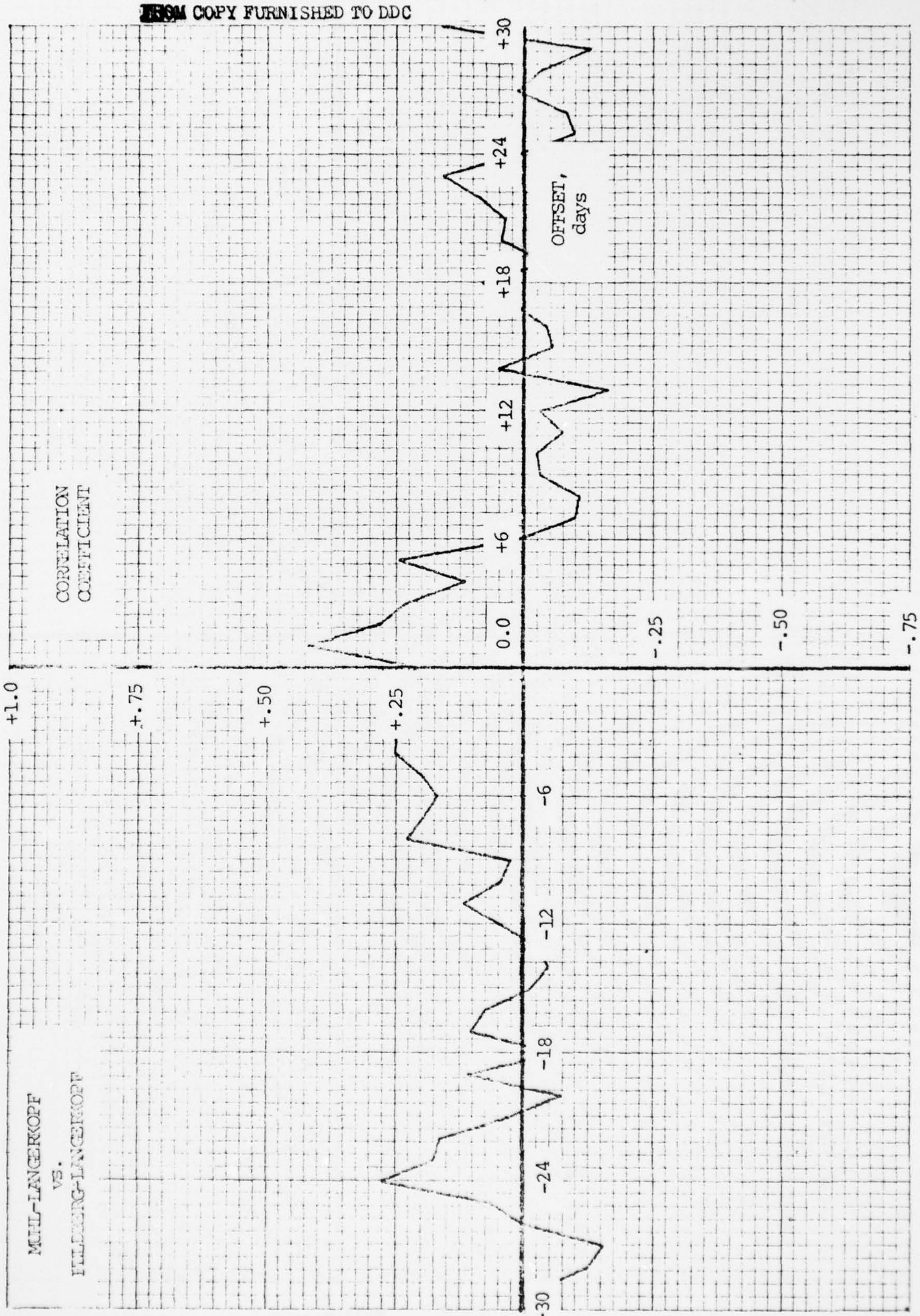
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